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GREAT BASIN NATURALIST MEMOIR

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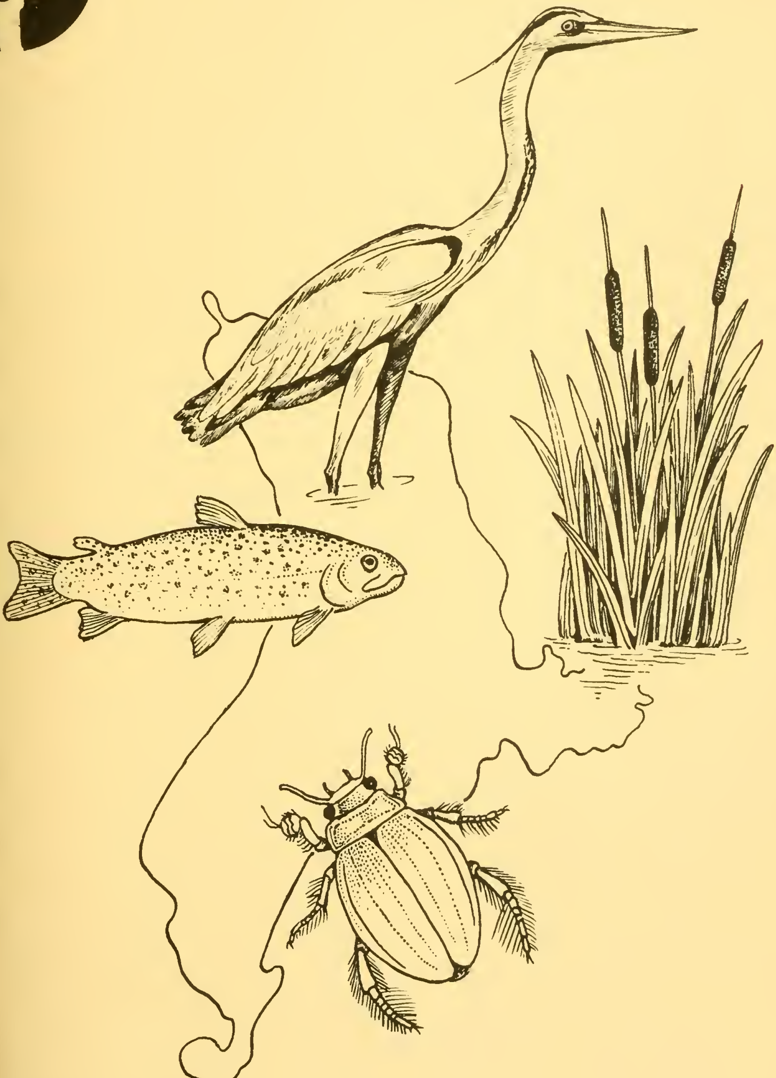
Utah Lake Monograph



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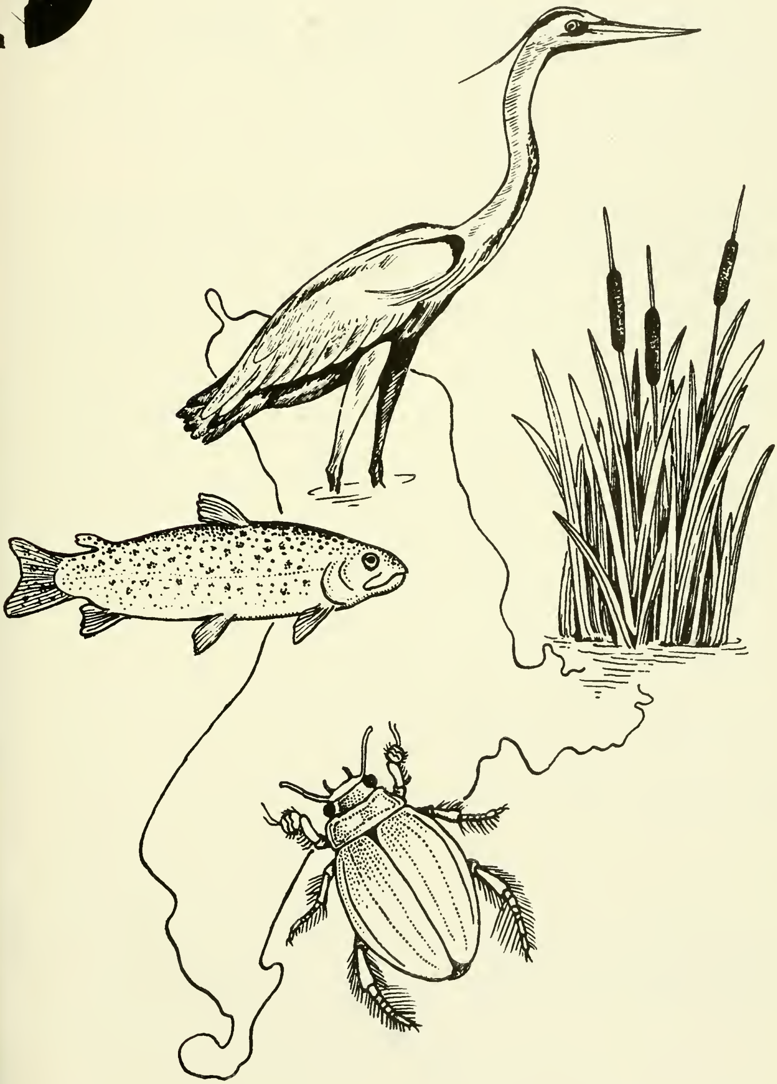

CONTENTS

Great Basin Naturalist Memoirs

Utah Lake Monograph

No. 5 Brigham Young University, Provo, Utah 1981

PREFACE

Richard A. Heckmann[1] and Lavere B. Merritt[2]

Utah Lake is the largest freshwater lake in the United States west of the Mississippi River. It covers approximately 39,000 ha (150 miles^2) and contains about $1.11 \times 10^9 m^3$ (900,000 acre-feet) of water. It is a remnant of Lake Bonneville, which occupied most of western Utah until about 7250 BC. The lake is fed by several streams, including the Provo and Spanish Fork Rivers, and is drained by the Jordan River into the Great Salt Lake.

The three groups of Indians, Paiutes, Utes, and Shoshones, that utilized the areas around Utah Lake were nomadic and used it primarily for fishing and hunting. They were largely displaced, commencing in 1849, by the Mormon pioneers, who tilled the land, spread the mountain streams for irrigation, introduced grazing animals, and effectively changed the natural balance of plants and animals. In an effort to increase the fish production, they also introduced several species of fish into the lake. Such actions profoundly affected Utah Lake and drastically modified its biota. Other uses of the lake included barge transportation, water transportation, boating, and recreation. At one time, 15 resorts existed around it. The aesthetic quality of the lake is an important element of Utah Valley.

In 1978 a group of biological and physical scientists met and discussed various questions that relate to Utah Lake—for example, what are the potentials for Utah Lake as a multiple-use resource? Is it possible through sound research and proper management to insure that future manipulation and use of the lake will be beneficial? Can maximum use of this resource be achieved and not detract from its utility and beauty? As a resource facing multiple demands, should any one use be given top priority? The consensus of the group was that the best way to approach these questions would be to prepare a volume that reviews and summarizes data pertaining to the lake. This goal is realized in the present volume.

This volume is divided into three parts: (1) the history of Utah Lake, (2) physical and climatic factors of the area, and (3) biology of the lake. Each article is written by invitation to scientists and historians who have made significant contributions to our knowledge of Utah Lake.

A wealth of renewable natural resources occur in and around Utah Lake. Not only can these resources be utilized now, but with proper management they will be available indefinitely. It is our hope that this volume will serve as a base for future studies of this valuable ecosystem. We feel strongly that Utah Lake should be carefully guarded and enjoyed, since it is a valuable asset to Utah Valley.

Acknowledgments

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College of Engineering Sciences and Technology, BYU Center for Health and Environmental Studies, BYU Departments of Civil Engineering, Geography, and Zoology, Provo-Jordan Parkway Authority, Eyring Research Institute, BYU Environmental Analysis Laboratory, and Utah Division of Wildlife Resources.

PHYSICAL AND CULTURAL ENVIRONMENT OF UTAH LAKE AND ADJACENT AREAS

Richard H. Jackson[1] and Dale J. Stevens[1]

Abstract.— Utah Lake and its surrounding area have a rich natural and cultural background. The moderate climate, abundant fresh water, and fertile soils of Utah Valley made it an oasis to aboriginal dwellers as well as to the present inhabitants. An overview of the physical setting, geology, climate, human use, and recent history of Utah Lake is presented.

Physical Setting

The basins and ranges of the Great Basin in the western United States have as their eastern border in central Utah a fertile valley rimmed by majestic mountains containing one of the largest freshwater lakes west of the Mississippi River. This lake, known as Utah Lake, occupies over 25 percent of the valley floor, and, even though it covers about 38,075 ha (150 mi^2) and contains approximately 1100 $\times$ 10^{6}m^3 (870,000 ac-ft) of water, its average depth is only 2.8 m (9.2 ft). The major perennial streams that feed the lake have their headwaters in the Wasatch and Uinta Mountains to the east. They are from north to south the American Fork River, Provo River, Hobble Creek, and Spanish Fork River. There are also a few minor perennial streams, many intermittent streams, and numerous springs and surplus water from pumped and flowing wells that add to the lake's volume. The total natural catchment area that drains water into Utah Lake is about 5957 km^2 (2300 mi^2). Demands for irrigation water in Utah Valley result in additional water entering Utah Valley from the Weber River, Duchesne River, and Strawberry River via diversion canals and tunnels. The annual surface flow into Utah Lake from all monitored sources is slightly over 640 $\times$ 10^{6}m^3 (520,000 ac-ft) (Hudson 1962:75). Location of the major surface streams that feed Utah Lake are shown in Figure 1. The Jordan River flowing into the Great Salt Lake is the sole outlet of Utah Lake.

The mountains that rim Utah Valley rise rather abruptly from the valley floor, reaching altitudes of about 457 m (1,500 ft) to nearly 2,286 m (7,500 ft) above the 1,368 m (4,489 ft) lake surface. In the lower parts of the valley a semiarid climate is found, but it gives way to wetter and cooler conditions higher up the mountain slopes. The highest peaks are well above timber line, but perpetual snow and ice are not found on any nearby mountain summits. Some snow banks remain from one year to the next, but most of these disappear during the average summers.

The different climatic types are reflected in the native vegetation zones from the valley floor to the mountain summits. Sagebrush and grasses dominate the lower areas, giving way to mountain brush, juniper and aspen, next to coniferous trees and eventually alpine grasses, and then sedges in the highest places. Trees and other riparian vegetation are found along most water courses, but much of the shore of Utah Lake is devoid of trees. The shallow margins of the lake contain a variety of vegetation, with Provo Bay being dominated by rushes and cattails.

Since settlement of the valley by people of European ancestry, most of the area has been transformed into cultivated land, cities, and towns. Of all the Great Basin valleys, Utah Valley is the most agriculturally productive. The mountain slopes still contain some natural vegetation, but man's activities have altered the area considerably. Dust storms occasionally add considerable particulate matter to the atmosphere, but man-made pol-

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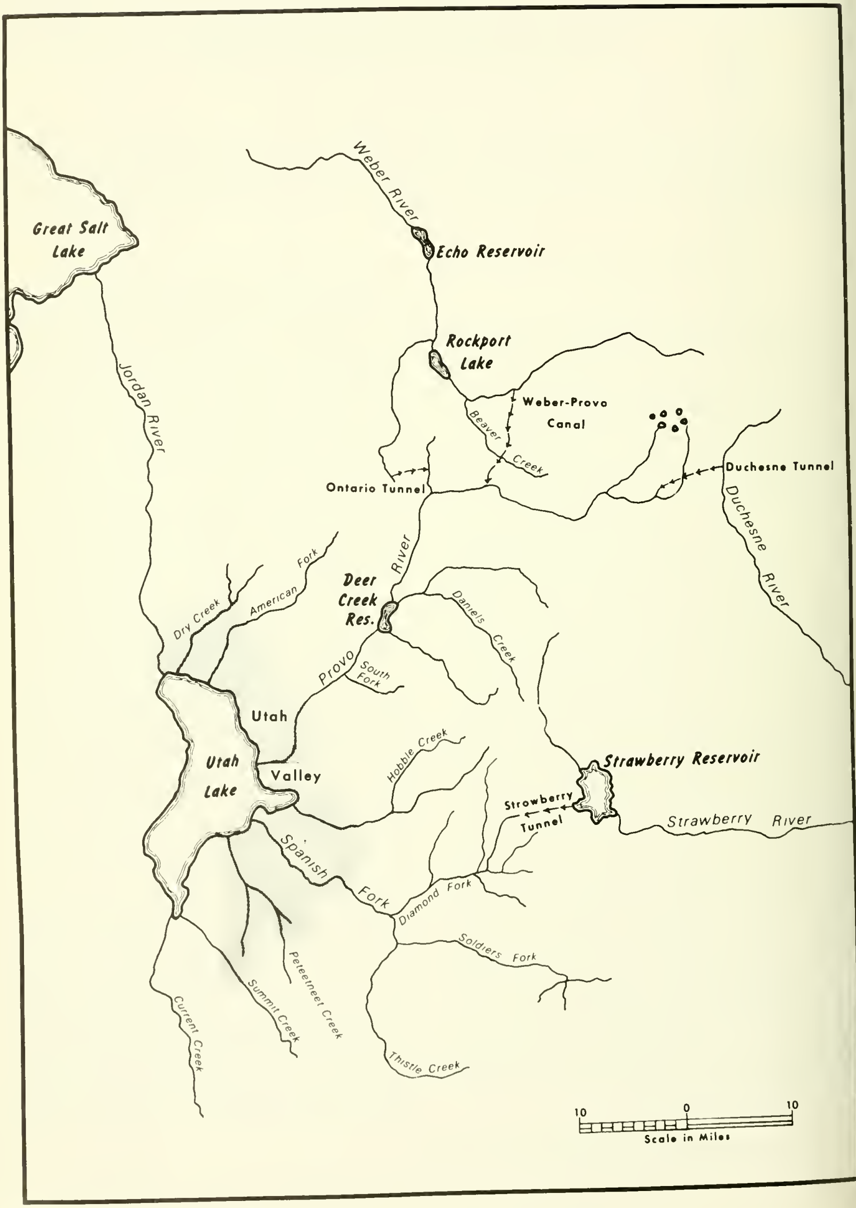

Fig. 1. Utah Lake drainage basin.

lutants tend to create a near-permanent haze over the valley, especially in winter months.

The name *Utah* (after the Ute Indians who were occupying Utah Valley when the first settlers came to the area in 1847) was first given to the county and the lake before it was applied to the territory and ultimately the state in 1896.

Geologic Origins

For the last 70 million years crustal stresses, marine erosion and deposition, and volcanic activity have all added to the character of the existing landscape. The Rocky Mountain system, including the Wasatch Range that borders Utah Valley and Utah Lake on the east, had its beginnings when two large sections (plates) of the earth's surface were forced together causing the existing sediments to be lifted to lofty mountains. This crustal deformation occurred over several million years, with periods of relative calm and downwear between the tectonic activity (Brimhall 1973:121).

About 35 million years ago volcanic activity, centered north and south of Utah Valley in the Tintic and Oquirrh Mountains, resulted in mineralization of these areas (Hintze 1973:80). Today the major mining districts of central Utah are centered in these areas. As time passed, further stresses caused blocks of the earth's crust to be uplifted and downfaulted. These uplifted blocks form the present mountains of the Basin and Range Province, with the Wasatch Mountains being the easternmost of the group. Many of the intermountain basins, such as Utah Valley, are downfaulted (grabens) and are filled with more recent marine and alluvial deposited sediments.

A distinct feature of the local block faulting is the high angle of the faults, which have created rather abrupt mountain fronts. Debris eroded from the uplifted ranges have gradually filled in the intermountain basins until today these sediments have accumulated to thousands of feet in depth in many basins. Perhaps the most unique aspect of the local faulting is the presence of numerous triangular faceted spurs in the proximity of the Wasatch fault zone. Interfluve ridges of the Wasatch Mountains that would normally extend to the valley floor are interrupted by recurrent fault lines at right angles to the ridge. Resulting faceted spurs or "flatirons" usually exist in somewhat of a hierarchy, with the largest and oldest occurring farther up the mountains from the smaller more recent triangle facets near the base. Maple Mountain to the east of Mapleton is a prime example of these faceted spurs.

The flatness of the floor of Utah Valley is due to lacustrine sediments of a much larger lake than Utah Lake. This large lake, known as Lake Bonneville, occupied much of western Utah until about 8,000 BC. It was one of several Pleistocene lakes in the western U.S. Some of the most conspicuous landforms in the vicinity of Utah Lake are the remnant terraces left by this ancient lake that probably began filling the valley about 75,000 years ago (Bissell 1968:11). Fluctuations in the level of the lake, caused by climatic changes, resulted in the formation of distinct terraces or benches on the mountainsides where the shoreline remained long enough to etch out and deposit beach sediments.

The first high level of the lake was at 1,555 m (5,100 ft) and is known as the Alpine Level (Bissell, 1968:3). The lake probably remained at this level for several thousand years before rising to 1,565 m (5,135 ft) due to wetter conditions. The water continued to rise to at least 1,585 m (5,200 ft) with the capture of the Bear River to the north, then spilled over through Red Rock Pass in southern Idaho into the Snake River. After tremendous volumes of water pushed on through the Snake and Columbia Rivers, the lake stabilized at the 1,463 m (4,800 ft) level (Bissell 1968:3). It was during this period that large deltas were built into the lake by the major inflowing streams, creating the "bench land" of eastern Utah Valley. This level has been designated as the Provo level.

As time passed, drier and warmer conditions prevailed and evaporation rates began to exceed the inflow rates, resulting in a decrease in size and, eventually, a separation into at least two distinct lakes. What is now Utah Lake remained as a temporary catchment basin for fresh water entering the larger Great Salt Lake via the Jordan River.

Layers of sand, gravel, silt, and clay underlay Utah Valley and correlate with several glacier periods when Lake Bonneville cov-

ered the area. Most of the gravel beds are associated with deltas and alluvial fan deposits that are adjacent to the mountain front. Silts and clays are more common in the central part of the valley (Brimhall 1973:2). The accompanying maps from a recent study (Figs. 2 and 3) show the general character of the lake bottom and the surrounding geology (Jensen 1972:41, 46). Because of the position of Utah Lake in the western part of the valley, its eastern shore is mostly poorly drained and has a gentle slope, but most of the western shoreland rises rapidly as the eastern front of the Lake Mountains.

Weather

The factors that account for the type of weather conditions and ultimately the climate in the vicinity of Utah Lake are:

1. Its inland position is 1,050 km (650 mi) from the Pacific Ocean and about 1,850 km (1,150 mi) from the Gulf of Mexico.
2. Its elevation above sea level is about 1,372 m (4,500 ft).
3. Its position is adjacent to the abrupt, sloping Wasatch Mountains.
4. The prevailing winds of the area are westerly.
5. Frequent frontal contact of polar and tropical air masses with accompanying cyclonic storms are experienced.

Because of the interaction of these factors, the precipitation in the vicinity of Utah Lake is relatively light, there is a wide variation in temperature, the relative humidity is normally low, there is abundant sunshine with some exceptions in winter and spring, and winds normally blow from the west to northwest, although there are frequent deviations from this direction. Early morning canyon downslope breezes move into the valley, especially from Provo and Spanish Fork Canyons. Advection fog often occurs in the winter months near the shore of Utah Lake and other lower portions of the valley. Snow depths in winter may reach up to 30 cm (11.8 in), with total snowfall averaging about 1 m (3.3 ft) per year. In 1972 Spanish Fork recorded a record total of 3.72 m (148 in) of snow. Snow depths are usually greatest in this southern part of the valley.

Although winds in excess of hurricane velocity (121 kph or 75 mph) are not common, they occasionally occur but are not associated with the tropical hurricanes that invade the southern coast of the U.S. Tornadoes are rare in Utah, but normally one or two are sighted per year in the state. None have been officially reported in the vicinity of Utah Lake. During the summer months dust devils (whirlwinds) carry dust and other debris into the air, but they rarely cause any damage. Winds blowing off the deserts to the west often bring with them considerable quantities of dust, which give a haze to the valley. If a rainstorm follows one of these dust storms, muddy rain can be expected.

Of all the elements of weather, precipitation and temperature are usually considered most important to the biotic community that is dependent on favorable quantities of each. Each of these will be discussed briefly.

Precipitation

The influx of moist air into the Utah Lake area usually originates over the Pacific Ocean during the winter and spring months and moves in with cyclonic storms usually originating in the Gulf of Alaska. These frontal storms are normally short-lived but occasionally result in more than 2.54 cm (1 in) of precipitation. As a cold front passes, the wind will normally shift from the south to the north. There is an obvious decrease in temperature, with gusty winds and rain or snow for several hours before the storm moves eastward and out of the area. Nearly 60 percent of the total annual precipitation occurs in the late winter and early spring, with March being the wettest month (Utah Climatological Data, 1950–1975).

The storm track moves northward during the summer months, and the change in pressure patterns allows moist air to move in from the Gulf of Mexico. Because of the relatively high temperatures of summer, convectional storms are more common than frontal storms. Thunder and lightning accompany the large cumulonimbus clouds, which may drop heavy amounts of rain and/or hail. Hailstones are usually less than 1 cm (0.4 in) in diameter. August is the wettest summer month, with receipts averaging about 2.54 cm (1 in) (Utah Climatological Data, 1950–1975).

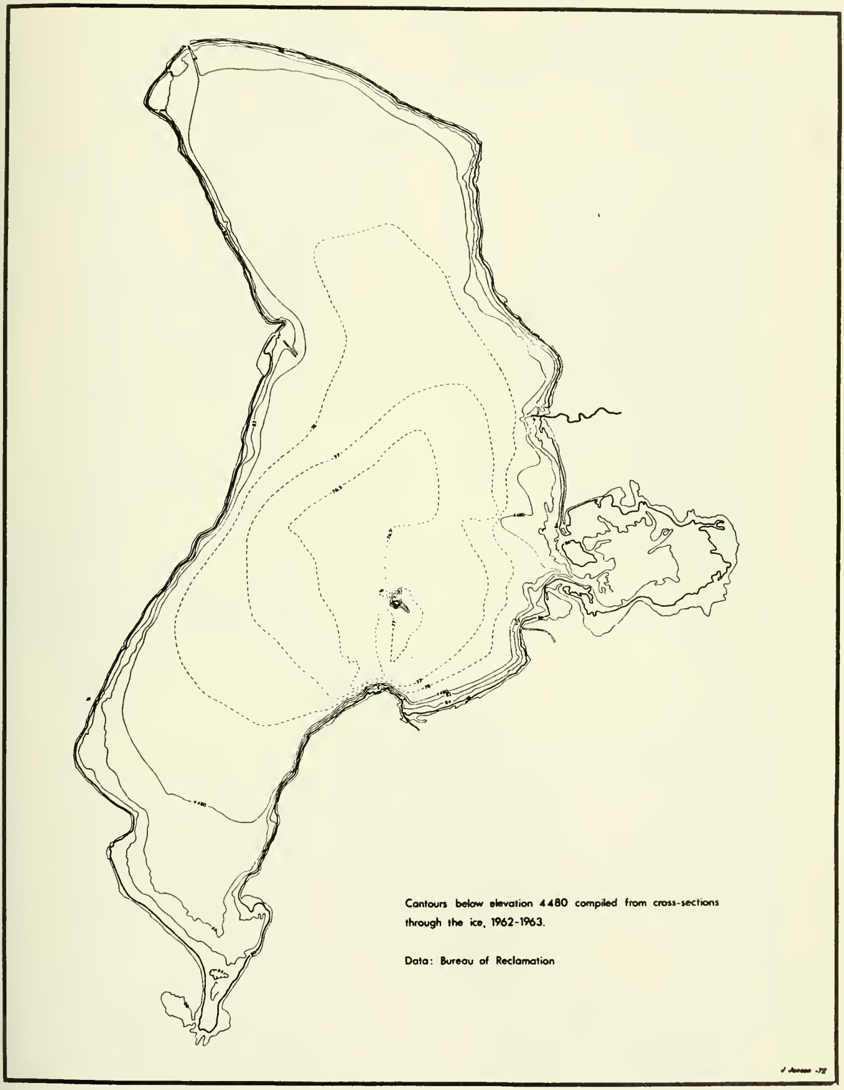

Fig. 2. Utah Lake topography.

During an average year, total precipitation varies from just over 23 cm (9 in) near the eastern shore of Utah Lake at the Geneva Steel Plant to over 45.7 cm (18 in) at Santaquin near the southern shore of the lake. In the nearby mountains, receipts averaging up to 127 cm (50 in) per year are common and are major source areas of Utah Lake water.

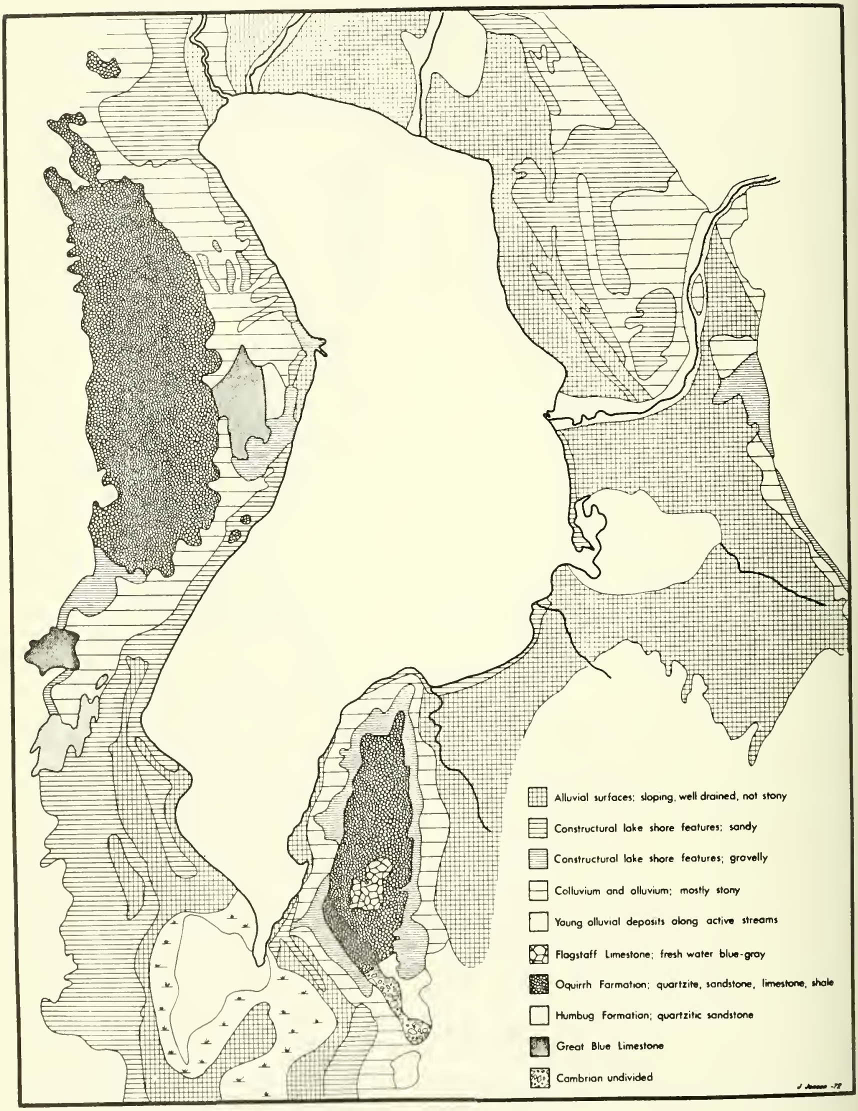

Fig. 3. Surface geology in the vicinity of Utah Lake.

Evaporation from Utah Lake, although considerable, seems to have no appreciable effect on local precipitation, although it does have some influence on humidity and temperature over and near the lake margins. Table 1 gives some monthly data on six stations that border Utah Lake (Utah Climatological Data, 1950–1975).

Temperature

Variation is perhaps the key word in describing temperature from place to place and from one season to the next in the valley. The transition from summer to winter and from winter to summer is usually quite rapid. There are distinct times of the year when springlike and autumnlike weather occur, but these "seasons" are best described in weeks of time rather than months. Average maximum July temperature is about 33 C (92 F), and the average minimum for the same month is 12 C (53 I). In the coldest month, January, the average maximum temperature is about 3 C (37 F), and the average minimum is approximately −10 C (14 F). Temperatures of over 38 C (100 F) are likely to occur during a few days of summer and drop to less than −26 C (−15 F) during a few days of the winter months (Table 1).

The geographical variation of temperature is seen in the growing season for three areas within Utah Valley. At Provo the growing season is 126 days; at Utah Lake-Lehi it is 132 days; and at Spanish Fork it is 167 days (Ashcroft 1963:28–33). Mountain and valley breezes and air inversion layers give partial explanation to these values, but location within the valley, proximity to the lake, altitude, etc., all help explain the differences. The charts below (Fig. 4) show probable dates of critical temperatures during the spring and fall for Lehi at the north end of Utah Lake and at the Provo Airport near the eastern shore.

Climate

Much of the early legend about the climate of central Utah and contemporary concepts nonresidents and residents alike have today about it is that Utah Valley is a desert (but may have been changed by man) or that it is part of a large desert that extends westward to the Sierra Nevadas. By all standards of measurement, however, Utah Valley is not a true desert. In fact, the eastern part of the valley is considered to have a humid climate.

A more apt description of the greater part of the valley is a cool winter steppe or semiarid climate. The boundary between this and the humid continental climate near the base of the Wasatch Mountains is determined by a comparison of total precipitation, including seasonal variation and potential evapotranspiration. Where the former is greater than the latter, a humid climate exists and vice versa.

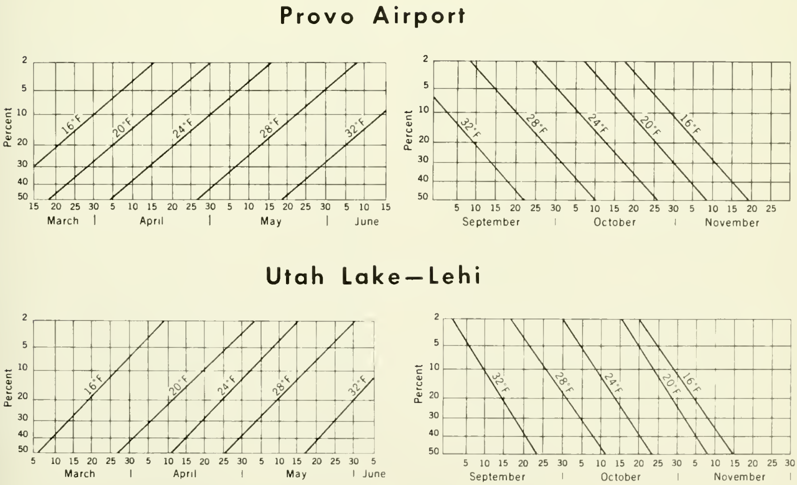

Fig. 4. Probabilities of first and last freezing dates at Provo Airport and Utah Lake-Lehi.

TABLE 1. Climatic Summaries for the Utah Lake Region.

TOTAL PRECIPITATION/MEAN SNOWFALL

	January	February	March	April	May	June	July	August	September	October	November	December	Annual
American Fork	1.74 / 14.4	1.54 / 8.6	1.74 / 8.4	1.81 / 2.4	1.68 / T	.92 / .0	.86 / .0	1.08 / .0	.96 / .0	1.50 / .4	1.31 / 4.0	1.65 / 12.4	16.83 / 50.8
Elberta	.82 / 12.2	.92 / 8.0	1.07 / 9.7	1.02 / 2.3	1.14 / 1.4	.63 / .0	.76 / .0	.77 / .0	.62 / T	1.06 / .7	.78 / 6.4	.83 / .0.0	10.42 / 50.0
Fairfield	.72 / 10.0	.70 / 5.2	.94 / 6.4	.87 / .5	1.27 / T	.96 / .0	.72 / .0	.96 / .0	.58 / T	1.37 / .4	.78 / 4.6	1.36 / 8.8	11.23 / 35.9
Lehi	.77 / 9.8	.94 / 6.3	.98 / 4.0	1.03 / 1.2	1.02 / .1	.68 / .0	.82 / .0	1.02 / .0	.68 / .0	.98 / .3	.82 / 2.8	.88 / 8.8	10.61 / 33.3
Provo Airport	1.49 / 18.9	.70 / 5.1	1.33 / 6.5	1.16 / .1	1.45 / T	.79 / .0	.50 / .0	1.12 / .0	.31 / .0	1.70 / .7	1.29 / 4.2	1.75 / 14.5	13.59 / 50.0
Spanish Fork	1.79 / 15.6	1.52 / 9.9	2.00 / 9.4	1.96 / 2.9	1.62 / T	.94 / .0	.82 / .0	.92 / .0	.92 / T	1.70 / .4	1.61 / 5.5	1.86 / 13.9	17.66 / 57.8

MEAN MAXIMUM/MEAN MINIMUM TEMPERATURES

	January	February	March	April	May	June	July	August	September	October	November	December	Annual
American Fork	37.0 / 19.9	43.2 / 24.7	51.2 / 30.3	61.8 / 38.4	71.4 / 46.6	81.2 / 54.2	89.7 / 62.5	87.8 / 61.4	78.8 / 53.0	65.4 / 42.6	49.4 / 30.7	39.0 / 23.2	63.0 / 40.6
Elberta	37.1 / 15.3	43.4 / 21.1	53.2 / 27.0	64.2 / 34.3	73.8 / 41.4	84.3 / 49.0	92.1 / 57.2	90.2 / 56.0	81.1 / 45.6	67.2 / 35.0	51.0 / 24.7	39.9 / 18.1	64.8 / 35.4
Fairfield	32.9 / 5.6	40.5 / 15.3	49.0 / 24.0	62.0 / 31.5	70.3 / 37.5	77.9 / 43.2	90.6 / 52.7	88.8 / 52.6	80.3 / 42.1	65.0 / 33.0	47.8 / 22.9	38.1 / 14.5	61.9 / 31.2
Lehi	35.4 / 12.5	42.1 / 22.0	50.0 / 27.5	61.7 / 34.4	71.5 / 41.8	80.4 / 47.4	89.0 / 55.6	86.2 / 53.9	77.0 / 43.7	64.2 / 34.1	48.5 / 24.8	37.4 / 17.4	62.0 / 34.6
Provo Airport	34.1 / 13.1	42.5 / 19.4	49.7 / 28.5	63.4 / 38.3	71.6 / 44.8	80.0 / 49.4	89.5 / 57.0	88.5 / 50.9	80.8 / 46.9	66.4 / 37.5	48.3 / 27.6	39.0 / 21.5	62.8 / 36.7
Spanish Fork	37.8 / 18.5	44.0 / 23.3	53.4 / 29.5	64.8 / 37.2	74.3 / 44.2	85.0 / 51.6	92.8 / 59.4	90.5 / 58.0	81.6 / 49.2	68.2 / 39.8	51.6 / 29.4	40.2 / 21.7	65.4 / 38.4

RECORDED MAXIMUM/RECORDED MINIMUM TEMPERATURES

	January	February	March	April	May	June	July	August	September	October	November	December	Annual
American Fork	64 / -15	70 / -15	77 / 5	85 / 15	94 / 29	108 / 32	108 / 40	102 / 40	100 / 31	87 / 19	72 / 0	70 / -12	108 / -15
Elberta	65 / -26	72 / -25	78 / 0	89 / 12	94 / 21	104 / 49	109 / 32	104 / 34	97 / 20	87 / 13	76 / -6	70 / -28	109 / -28
Fairfield	55 / -31	60 / -21	77 / 2	88 / 13	91 / 16	96 / 25	104 / 33	99 / 32	98 / 25	85 / 16	70 / 3	59 / -21	104 / -31
Lehi	57 / -26	63 / -28	77 / 1	84 / 14	90 / 21	102 / 30	106 / 38	100 / 33	94 / 18	85 / 10	72 / -3	63 / -25	106 / -28
Provo Airport	57 / -25	67 / -20	74 / 9	87 / 24	92 / 28	93 / 35	99 / 42	99 / 42	98 / 28	88 / 22	75 / 5	61 / -15	99 / -25
Spanish Fork	63 / -16	68 / -17	80 / 1	87 / 10	93 / 20	104 / 31	108 / 38	104 / 39	98 / 29	87 / 11	79 / -1	65 / -19	108 / -19

MEAN TEMPERATURES

	January	February	March	April	May	June	July	August	September	October	November	December	Annual
American Fork	28.5	34.2	40.8	50.2	59.0	67.6	76.1	74.6	65.9	54.0	40.1	31.3	51.8
Elberta	26.2	32.2	40.1	49.2	57.6	66.7	74.6	73.0	63.4	51.2	38.0	29.0	50.2
Fairfield	19.3	27.9	36.5	46.8	53.9	60.5	71.6	70.7	61.2	49.0	35.4	26.3	46.6
Lehi	23.9	32.0	38.7	48.1	56.6	63.8	72.3	70.1	60.4	49.2	36.6	27.4	48.2
Provo Airport	23.6	30.9	39.1	50.9	58.2	64.7	73.2	72.2	63.9	52.0	37.9	30.3	49.7
Spanish Fork	28.2	33.6	41.4	51.0	59.2	68.3	76.2	74.2	65.4	54.0	40.6	31.0	52.0

Other Natural Features

Besides climate and land surface forms, soils and biota should be included in any discussion of the local physical geography. Because man has used and altered the more desirable areas of Utah Valley for crop production, towns, etc., the natural soil and biotic systems have been disturbed considerably since the early settlement period. The first settlers found most of the valley covered with grasses except where streams provided enough extra water for trees and other riparian vegetation. The hill slopes were probably not too different from what one sees today except there was less sagebrush and probably more grass on the lower slopes. In their quest to establish a permanent home here, the settlers tilled the land, spread the mountain streams over the soil to irrigate their land, grazed the hill slopes, and effectively changed the natural balance of plants and animals. They both inadvertantly and purposely introduced many varieties of plants and animals that formerly did not exist here.

The most recent soil survey of Utah County lists six soil orders in the study area. The most dominant are the Mollisols, which have a thick, dark-colored surface layer that is 1 percent or more organic matter and a base saturation of 50 percent or more (Swenson et al. 1972:134). Most of the good farm land is of this type. Other orders that are found here are Alfisols, which are poorly drained soils with saline or alkaline conditions; the Histosols, which are bog soils found near the lake shore and other marshy areas; and Aridisols, which are found in the drier places. Aridisols have a strong lime horizon within 100 cm (40 in) of the surface, and Inceptisols and Entisols are soils that have only recently begun to develop because of recent deposition of alluvium (Swenson et al. 1972:134–136, 164).

The irrigated farm land of Utah Valley produces alfalfa, grain, and corn silage as main crops. Much of the bench land is planted to fruit trees, especially cherries, peaches, apples, and pears. Home gardens are quite common, and many varieties of vegetables and fruits are grown in these noncommercial ventures.

Most of the natural vegetation has been replaced by cultivated crops, imported weeds, and landscaped yards with their wide varieties of plants. In spite of the abovementioned changes, Utah Valley is an impressive place to view after having traveled through surrounding areas. The Spanish fathers named it Paradise Valley in 1776. The current residents may not call it by such an exotic name, but it does have many amenities that make it stand out like an oasis in a desert.

HUMAN USE

Utah Lake and its associated streams and lake plains have been of importance to man for at least several millenia. The earliest known inhabitants of the lake plain area were the so-called desert culture of the American Indian peoples (Jennings 1960a:4). The desert culture people occupied the Great Basin and the valleys at the foot of the Rocky Mountains in the period from approximately 10,000 BC to 300–500 AD (Jennings 1960a:4). Evidence of the desert culture has not been discovered in and around Utah lake, but remains of the desert culture group have been found at Danger Cave in western Utah dating from approximately 8,000 BC (Jennings 1960a:8). The desert culture people were limited in numbers and led a life devoted to a search for food in the Great Basin and the rivers and streams and lakes associated with it. Their use of Utah Lake was restricted to hunting for game on the plains of Utah Valley and to occasional catching of fish in the rivers during spawning season (Montillo 1968:39).

The basic culture in the Utah Lake area for which extensive archaeological evidence has been discovered is the Fremont culture (Wormington 1955). In the Utah Valley area, the Fremont culture consisted of small groups engaged in the production of corn, squash, and beans; hunting and gathering; and relatively intensive fishing by those residing adjacent to Utah Lake. The lakes and rivers entering it were important sources of fish for the Fremont culture, as evidenced by bones found in archaeological sites on and around the lake (Montillo 1968). These Indians caught fish in the streams primarily during the spawning season. Numerous sites

of the Fremont culture exist around the shores and river mouths of Utah Lake. At least 36 sites have been located on the Provo River in the area west of present-day Provo (Montillo 1968:6). Other sites have been found on the lower Spanish Fork River, Goshen Bay, the Peteetneet River near Payson, the American Fork River, and the Jordan River, as well as at sites along the lake shore (Jennings 1960b:212).

The Fremont culture occupied the area around Utah Lake from 800 to 1600 AD (Montillo 1968:34), until the great drought of 1400 led to difficulty in subsistence, and the Fremont culture groups ultimately moved to the central plains of the United States (Montillo 1968:35). Following the migration of the Fremont culture, other Indian groups moved into the area.

At the time of occupation of the area by Anglos in the mid-1800s, three groups of Indians utilized the area around the lake. These represented the Paiute groups from the western side of Utah Lake and the Great Basin, the Ute Indian tribes periodically occupying the Utah Lake plains and the Provo, Spanish Fork, and American Fork river areas on the eastern shores as they migrated; and the Shoshone Indians, whose center was north in the Cache Valley, but who occasionally came into the area. These groups were nomadic and utilized the lake and rivers entering it for hunting and fishing.

The first written records relating to Utah Lake and adjacent lake plains come from the records kept of the Dominguez and Vélez de Escalante expedition. Dominguez and Vélez de Escalante left New Mexico in late July 1776 in search of a direct route to Monterey, California. In the course of their travels they came down Spanish Fork Canyon and into Utah Valley, entering the valley on 23 September 1776 (Jensen 1924:17–20). Dominguez and Vélez de Escalante provided a description of the Indian residents of the lake at the time of their arrival and indicated the importance of fishing to the Indian people. Because of the reliance of the people on fish, Timpanogotes, as Domingues and Véles de Escalante referred to them, were called fish eaters by other Indian groups (Jensen 1924:32). The Indians (the Timpanogotes) were said to have customs that resembled the western Shoshone and southern Paiute tribe (Steward, p. 40). Other authors maintain that the tribes found near the lake consisted of the Shoshone language group but were actually made up of Paiute, Goshiute, and Ute divisions. The Goshiutes were located in the area west and north of the lake, the Paiutes to the south and west of the lake, and the Ute tribes near the eastern side of the lake representing the Timpanogotes Indian tribe proper (Jennings 1960a:21). The importance of fish in the Indian life-style is brought out by the reference by other Indians to them as fish eaters and by the fact that, before leaving Utah Valley, Dominguez's party purchased a large quantity of dried fish for supplies on their return journey (Jensen 1924:23). Although it is impossible to reconstruct the use of the lake and rivers by the native population, it is evident that the lake played a central role in the life of the people who resided near it prior to its occupancy by Anglos.

Anglo Accounts of the Lake and Environs

Dominguez and Vélez de Escalante's exploration and associated journal represents the earliest available recorded description of Utah Lake and its environs. Judging from their descriptions of the area, the Dominguez party was much more interested in the land around the lake than the lake proper. Since the Spaniards were interested in creating agricultural settlements, the fertile, well-watered lake plains received the bulk of their attention. Dominguez described the lake and the area around it as follows:

> On the northern side of the San Buenaventura River, as we said before, there is a ridge of mountains, and from what we could see of it, it runs from northeast to southwest more than seventy leagues. In its widest part it is more than forty leagues, and where we crossed it, perhaps thirty. In this ridge, on the western side, at 40°49′ latitude, northwest, a quarter north of the town of Santa Fe, is situated the Valley de Nuestra Senora de la Merced de los Timpanoautzis, surrounded by the highest peaks of the ridge from which four medium-sized rivers descend which irrigate the valley, flowing until they enter the lake which is in the center. The plain of the valley from southeast to northwest extends about sixteen Spanish leagues [one Spanish league equals 2.63 miles] and from northeast to southwest ten or twelve leagues. It is all clear land except for the marshes by the side of the lake where the soil is good for every kind of planting.
>
> Of the four rivers which irrigate the valley, the first one on the southern side is the Aguas Calientes River [Spanish Fork] in whose extensive valleys there is

ground enough, easily irrigated, for two large towns. The second river, going north, three leagues from the first one, is more abundant and can support a large town or two smaller ones, there being much good soil, easily irrigated. This river, before emptying into the lake, is divided into two branches. On its banks, in addition to the poplars, there are tall alder-trees. We named it the San Nicolas River [apparently Spring Creek and Hobble Creek]. Three leagues and a half northwest is the third river, of flat valleys with good soil for planting. It is more abundant than the two above mentioned; it has large poplar groves and valleys of good soil with sufficient water to support two or even three large towns.

We spent September 24 and 25 by its bank and named it the San Antonio de Padua River [Provo River]. We did not reach the fourth river, though we could see its poplar groves. It is situated northwest of the San Antonio River, and it has on this side much flat and seemingly good soil. They told us it has as much water as the others, and therefore, several settlements or villages could be established by it. We named it the Santa Ana River [American Fork River]. In addition to these rivers there are in the plain many springs of good water and several springs which issue from the mountains.

Throughout the valley there is much good pasture and in some places flax and hemp grow in such abundance that it seems as though they had been planted deliberately. The climate is also good here because after suffering from the cold from the time we left the San Buenaventura River, now, night and day, throughout the valley, we feel very warm. Besides these excellent natural features, the surrounding mountains contain sufficient timber and firewood, many shelters, springs and pasture lands to raise cattle and horses. All this is true of the north, northeast, east, and southeast parts. On the south and southwest there are two other extensive valleys, also with abundant pasture and sufficient water. The lake extends to one of these valleys. It may be about six leagues wide and fifteen long and runs northwest. By means of a narrow opening, according to what they told us, it unites with others very much larger. The Timpanogotzis Lake is teeming with several kinds of edible fish, in addition to geese, beaver, and other land and water animals, which we did not see.

. . . With three fortresses and three towns inhabited by Spaniards in communication with the forts, the door will be opened to a new empire which can be explored and populated.

The base where the principal objective of the enterprise should be established is the valley and the borders of the Lake of the Timpanogos near one of the rivers which water the valley, because this place is the most pleasant, beautiful, and fertile in all of New Spain. It is large enough in itself to support a city with as large a poulation as that of Mexico City and its inhabitants can enjoy many conveniences because it contains every necessary thing for the sustenance of human life. The lake and the rivers which empty into the lake abound in many kinds of choice fish; there are to be seen there very large white geese, many varieties of duck, and other kinds of beautiful birds never seen elsewhere; beavers, otters, seals, and other animals which seem to be ermines by the softness and the whiteness of their fur. In the valleys of these rivers there is much uncultivated hemp and flax (Auerbach 1943).

The description of Utah Lake by the Spanish does not indicate whether the lake is clear or muddy or any of its other physical characteristics. Compared to the New Mexico area from which they had traveled, the lake and its adjacent fertile plains with the numerous streams entering it must have indeed presented a highly favorable spot. The fact that the water entering the lake and the lake itself were fresh, and that it provided an abundance of fish, met the purposes of the Spanish. The land on the lake plains would be the center of any settlements they established and, therefore, descriptions of the lake were secondary. It should be noted, however, that Dominguez did indicate that settlers should include carpenters who could build boats for use in navigating the lake and further exploring it to discover its utility (Auerbach 1943). The Spanish under the direction of Dominguez and Vélez de Escalante never returned to Utah Valley, and further information concerning the lake and its environs was not written until fur trappers visited the area in the early 1800s.

Recorded evidence seems to indicate that either William H. Ashley of the Rocky Mountain Fur Company or Jedediah Smith were the first early fur trappers to visit the lake. William Ashley is reputed to have visited the lake in 1825 (Bancroft 1889:21), but some scholars question whether he actually reached the Utah Valley area or whether the lake he visited was actually the Great Salt Lake (Dale 1918:155,168). Because of Ashley's purported visit to Utah Lake, the name Ashley Lake has occasionally been used in referring to the lake (Dale 1918:187). If Ashley did in fact visit Utah Lake, he left no written account of it. At least one other fur trapper, Etienne Provost, visited Utah Lake in the period of 1824, and from him the Provo River and Provo City take their names (Jensen 1924:28–29). Daniel T. Potts, a trapper with Ashley's Rocky Mountain Fur Company from 1822 to 1827, recorded of Utah Valley, "This is a most beautiful country. It is intersected by a number of transparent streams. The grass is at this time from six to twelve inches in height and in full bloom" (Frost 1960:62). Other trappers who visited the Utah Lake area left no written accounts on which to base an understanding of the lake and its characteristics.

John C. Fremont, a government explorer, visited Utah Valley in 1843 as his party returned from California. In addition, Fremont visited Utah Lake in another party in 1845. Fremont described the Utah Valley area as follows:

> In this cove of the mountains along its [Utah Lake] eastern shore, the lake is bordered by a plain where the soil is generally good, and in greater parts fertile; watered by a delta of prettily timbered streams. This would be an excellent locality for stock farms; it is generally covered with good bunch grass and would abundantly produce the ordinary grain (Fremont 1845:258).

Fremont's account represents the last of the intermittent Anglo visitors to Utah Lake. Shortly after his visit, the Mormon pioneers entered the Salt Lake Valley and began permanent colonization.

Mormon Settlement and Use in the Utah Lake Plain Area

The Mormon settlement of the Great Basin in 1847 represented the first permanent white occupation of the region around Utah Lake. The leader of the Mormon pioneers, Brigham Young, received his first report of Utah Lake while en route to the Salt Lake Valley in 1845 during an encounter with Jim Bridger. Brigham Young hoped that Utah Lake would provide sufficient fish to augment the settlers' cattle (Wride 1961). After the arrival of the Mormons in the Salt Lake Valley and initial settlement of that area, an exploring party was sent to the Utah Lake area in December 1847. Under the direction of Parley P. Pratt, this small exploring group brought a wagon and boat into Utah Valley and attempted to fish on Utah Lake, then explored the surrounding area. Pratt notes that, after traveling into Utah Valley, they arrived at

> . . . the foot of Utah Lake, a beautiful sheet of fresh water, some 36 miles long by 15 broad. Here we launched our boat and tried the net, probably the first boat and net ever used on this sheet of water in modern times. We sailed up and down the lake shore on its western side, but had only poor success in fishing. We, however, caught a few samples of mountain trout and other fish. After exploring the lake and the valley for a day or two, the company returned home, and a Brother Summers and myself struck westward from the foot of the lake on horseback on an exploring tour (Jensen 1924:31).

As a result of Pratt's favorable report of Utah Valley and continued population growth in the Salt Lake Valley, the Mormon leadership began plans for settling Utah Valley in late 1848. In March 1849 a group under the direction of John S. Higbee, who had previously visited the Utah Lake area with Parley P. Pratt, came into Utah Valley and settled on the Provo River slightly west of present-day Provo City. The fort which they constructed represents the first Anglo settlement on the shores of Utah Lake. Associated with this settlement was the cultivation of common agricultural crops, with related diversion of water from the Provo River (Jensen 1924:33–38).

During the same year additional communities were founded around the lake on Battle Creek (Pleasant Grove) and Lakeview. The following year an additional six communities were founded—American Fork, Lehi, Payson, Spanish Fork, Spring Lake, and Springville (Table 2). It should be noted that by 1851 there were settlements along all the streams entering Utah Lake, and by the 1860s essentially all the communities in the area had been founded.

Population growth in the region was based on agriculture and did not increase rapidly until after the 1940s. Little is known of the views of Utah Lake by the early settlers other than their statement that it was a freshwater lake. Since the initial colonists and explorers were coming from the Salt Lake Valley, this was the most important factor when compared to the saline Great Salt Lake. Since the freshwater streams provided culinary water, the settlers were never seriously concerned about the relative quality of the water within the lake proper. Likely the lake itself was approximately the same as at the present in terms of amount of sediment suspended in the water and associated turbidity (Brimhall and Merritt 1976). A report in the early 1900s indicated that the water was cloudy and opaque three to six inches below the surface, which is similar to its present condition (Huber 1972:57). Although the settlers re corded few impressions of the lake, Utah Lake and its associated streams were of paramount importance to them.

Mormon Use of Utah Lake and Associated Streams

Fishing from Utah Lake and adjoining streams was one of the primary uses of the lake by the Mormon settlers. On 6 January

TABLE 2. Settlement and population growth of communities around Utah Lake.

Settlement	1860	1870	1880	1890	1900	1910	1920	1930	1940	1950	1960	1970
Alpine, 1851 (Mountainville)	135	208	319	466	520	496	407	509	441	571	775	1047
American Fork, 1850 (Lake City, McArthurville)	695	1115	1299	1942	2732	2797	2763	3047	3333	5126	5373	7713
Benjamin, 1860			150	417	661	580	575	619	674	706		
Elberta, 1895 (Mount Nebo)					153		300	278	151	138		
Genola, 1935							194	321	325	314	380	424
Goshen, 1857 (Sodom, Sandtown, Mechanicsville)			394	298	645	470	526	669	616	525	426	459
Highland					195	171	247	277	270			
Lakeshore				390	582	528	457	482	528	523		
Lakeview, 1849				376	276	344	391	400	460	446		
Lehi, 1850	831	1058	1490	1907	2719	2964	3078	2826	2733	3627	4377	4659
Linden, 1925								589	587	801	1150	1644
Mapleton					584	534	586	663	907	1175	1516	1980
Orem, 1920								1915	2914	8351	18394	25729
Palmyra									262	236		
Payson, 1850	830	1436	1788	2135	2636	2397	3031	3045	3591	3998	4237	4501
Pleasant Grove, 1849 (Battle Creek)	526	930	1775	1926	2460	1618	1682	1754	1941	3195	4772	5327
Provo, 1849 (Fort Utah)	2030	2384	3432	5159	6185	8925	10303	14766	18071	28937	36047	53131
Salem, 1856 (Pondtown)	180	353	510	527	894	693	609	610	659	781	920	1081
Santaquin, 1851 (Summit Creek)	158	602	715	769	889	915	976	1115	1297	1214	1183	1236
Spanish Fork, 1850	1015	1450	2304	2214	2735	3464	4036	3727	4167	5230	6472	7284
Spring Lake, 1850			157	93	232	188	252	300	453	495		
Springville, 1850 (Hobble Creek)	1357	1661	2312	2849	3422	3356	3010	3748	4796	6475	7913	8790
Vineyard					398	435	560	543	719	267		

1849 a party of six men was sent to fish Utah Lake by Brigham Young, but they were unsuccessful in obtaining quantities sufficient to justify continued fishing efforts (Crawley and Knecht 1964:29). After settlement of Provo in 1849, fishing became an important part of the subsistence economy practiced by the settlers. Spawning fish in the lower Provo River

and adjacent areas of Utah Lake were caught and utilized fresh, dried, or salted in barrels for later use (Huntington 1960). With the passage of time, increased fishing took place on the streams entering Utah Lake (Gardner 1913).

Since it was the custom of the Indians in the area to fish the streams during the spawning season of the lake fish, they found the presence of the Mormon settlers and their extensive fish catch an unwelcome competition as early as 1853 (Armstrong 1855:203–209). In the spring of 1855, when the Indians arrived, the Indian agent noted that "the Utah Lake and Provo River at this season of the year abound in fish known as mountain trout, and it is for the purpose of fishing that so large a number of Utah tribes of Indians resort hither every spring." According to the Indian agent, the Indians attempted to take fish through trapping, using of bows and arrows, and catching them with their hands in the riffles, but were unable to do so because of the competition from Mormon settlers who were using nets and seines to catch fish. As a result of the high water and the settlers' efforts, the Indians felt they could not obtain sufficient fish for drying, and the Indian agent arranged for the settlers to catch fish for the Indians' use. "At the insistence of some of the chiefs, I requested one of the fishing companies to fish for them, which request the company immediately complied with, and after some days successful fishing, they loaded the packhorses of the Indians with large quantities of fish." (Commissioner of Indian Affairs 1855:202–203).

By 1856 one group of settlers had begun a commercial fisheries establishment that caught fish for use in the Utah Valley and Salt Lake area throughout the year (Carter 1975:8). The lake continued to be an intensive source of fish for the settlers of Utah Valley in the period from 1856 to 1860 as regulations were promulgated by Provo City and other communities to regulate the fisheries of both the lake and streams entering into it. An ordinance for control of fishing privileges passed at the Provo City Council meeting on 6 August 1853 is the earliest recorded evidence of control of the fishing (Jensen 1924:83–84).

By the late 1860s and early 1870s, however, the number of commercial fishing groups declined and fishing activity began to decrease as a result of diverting water from the streams for irrigation and the associated loss of fish population. The fishing continued on Utah Lake and adjacent streams through time, as indicated in Table 3's brief outline of the fisheries of Utah Lake to 1904 (Carter 1975:8–16). Fishing and fishing activities on Utah Lake were as significant to the Mormon settlers of the valley as they had been to the American Indians previous to the Mormon settlement.

The single most important use of Utah Lake and the streams associated with it was for water for irrigation purposes (Fig. 1). As each community was established, primitive diversions were made to carry irrigation water to adjacent fields. Two canals were developed in Provo city in 1850 for irrigation of fields in the area of present downtown Provo. The first was the Turner ditch, which watered approximately half a square mile, and second was the East Union ditch, which carried water to the foothills east of the present downtown area (Jensen 1924:63). As time passed, these systems were expanded and water was diverted higher up the stream to bring additional land under the ditch for irrigating. By 1874 all the summer low flows in the streams had been appropriated and disputes began as to who actually controlled the rights to the waters that had been claimed or utilized.

Some idea of the extent and rapidity of water diversion is evident from the fact that by 1869 one-third of the ditches and laterals found in Utah Valley in 1920 had been completed (U.S. Bureau of Census 1920). Also by 1869 there were five major canals taking water from the Provo River. In addition, the so-called Highline Canal was under construction; it followed the base of the mountains from Provo Canyon to the bench areas along the eastern bank of Provo River. At the same time American Fork River had four major canals taken from it, one to American Fork, one to Lehi, one to Pleasant Grove, and one to the area north of these communities. Dry Creek had canals taking water to the Lehi area and to the vicinity of present-day Alpine; Hobble Creek had three canals divert-

TABLE 3. Brief annotated history of the fisheries of Utah Lake, 1849–1900

Date	Activity
1849	Beginning of commercial fishery in Provo River and Utah Lake.
1850–52	Spawning fish in rivers and streams still caught.
1856	Rapid increase in commercial fishing with year-round harvest, long seines introduced. Selling of fish common in Utah Valley and Salt Lake Valley. State, county, and local governments begin some regulation of fishing. Provo City regulated the Provo River, while Utah County regulated fisheries of Utah lake and other streams (Spanish Fork, Jordan River, Payson Creek, and Provo Bay streams).
1860–70	Decline in the number of commercial fishing groups; consolidation of fishing areas.
1863	Jens Michelson begins long-term fishery, mouth of Spanish Fork River.
1870	The fishing decline was noticed and a special committee was appointed in 1870 at the general conference of the LDS Church to develop fish culture.
1872	Yarrow and Cope visited and felt the trout fishery had declined one-third. Several court cases on mesh size of seine and unlicensed fishermen.
1875	Continued decline in catch; still a ready market.
1876	Territorial legislature bans seining and poisons or explosives, and requires a fish passageway in all dams.
1878	First Utah County fish and game commissioner appointed.
1880	Entrances of all irrigation canals should be screened.
1882	Lawful to fish with seine 200 yards long by 12 feet wide, mesh 2 inches center and 1½ inches in wings.
1884	Mesh size reduced to 1½ inches for 50 feet center.
1886	Screen law for irrigation ditches repealed because cleaning screens a nuisance. Carp introduced into Utah Lake.
1888	Season established from 1 October to 1 June to legally seine or hook and line fish for trout.
1890	Territorial game warden appointed. Largemouth bass introduced into Utah Lake.
1890–94	Black bullheads, channel catfish introduced into Utah Lake.
1894	Most of trout shipped out of territory. Suit brought in Utah County court to halt practice.
1895	Largemouth bass become very common in Utah Lake.
1897	Only carp, chubs, mullets, and suckers can legally be taken by seine.
1897	Mills, factories, power plants, and manufacturing concerns required to install fish screens in intake canals.
1897	Unlawful to seine within one-half mile of inflowing river into Utah Lake.
1899–1904	Around 500,000 pounds of fish (mostly no trout) from Utah Lake shipped out of state.

ing water to the Springville and Mapleton areas; and Spanish Fork River had five canals diverting water to irrigate much of the area in the central and southern portions of Utah Valley. In addition, canals of undetermined number also diverted water from Santaquin and Peteetneet Creeks by 1869 (Griffin 1965:41–43). Later, larger dams were constructed farther upstream to divert water to higher areas around Utah Lake and/or to store water. Figure 5 indicates the major irrigation canals in the vicinity of Utah Lake at present.

Of the four larger rivers that flow into Utah Lake, Provo River brings more than one-half the total water flow into Utah Valley. The natural flow of the Provo River at its entrance to Utah Valley averages approximately $358 \times 10^6 m^3/yr$ (290,000 ac-ft/yr) (Hudson 1962:80). Man-made modifications to this flow include 14 small reservoirs on the headwaters of the Provo River, totaling $12.3 \times 10^6 m^3$ (10,000 ac-ft) of storage constructed prior to 1910 and diversions from other drainage basins. The Weber-Provo Canal is the largest of the intrabasin transfers and brings water from the Weber River basin into

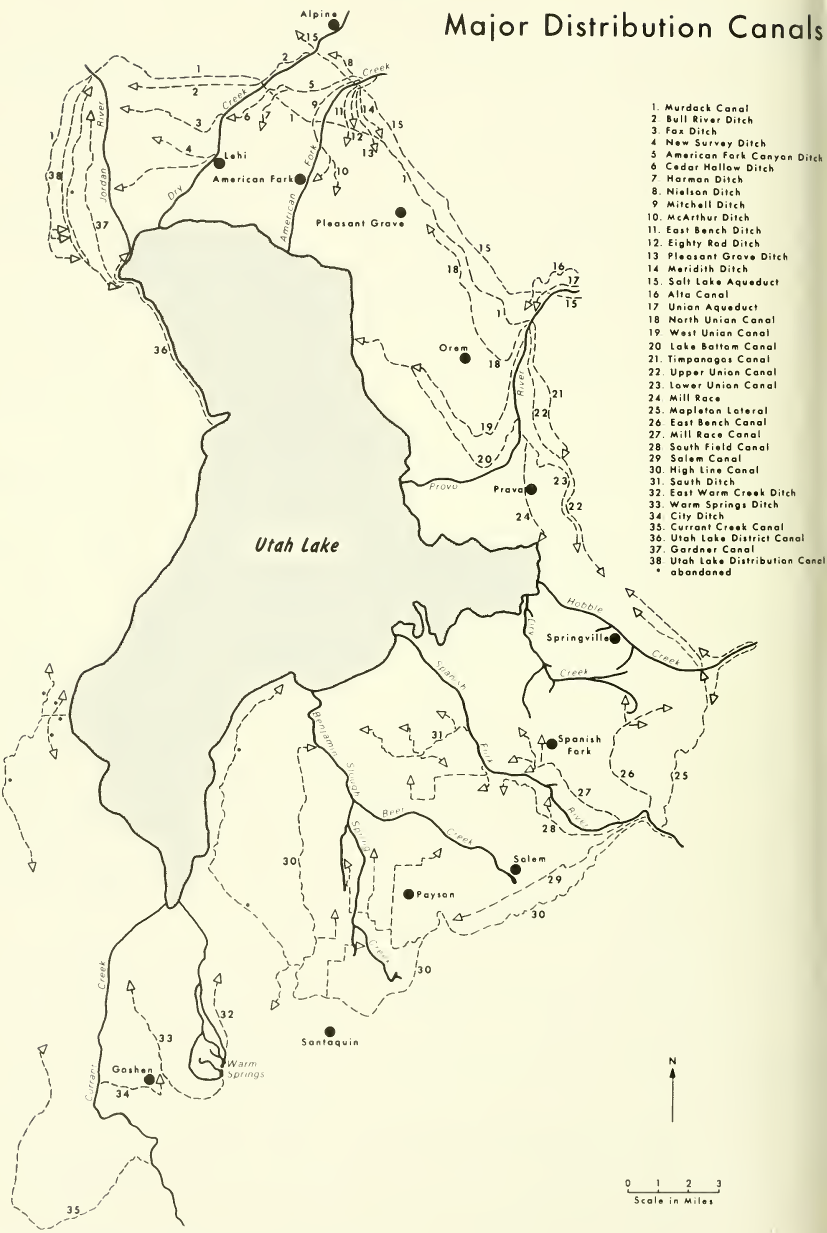

Fig. 5. Major distribution canals in the vicinity of Utah Lake.

the Provo River drainage basin. The canal was originally built in the 1920s and was later enlarged in 1947–1951 as part of the Deer Creek project. The annual amount delivered to the Provo River varies from 41 × 10^6 to over 93 × 10^6m^3 (33,000 to over 75,000 ac-ft), depending on the amount of precipitation in a given year (Hudson 1962:82–83). In addition, water is transferred from the Utah Lake drainage basin to the Great Salt Lake drainage basin by means of the Salt Lake aqueduct, which takes between 26 × 10^6 and 33 × 10^6m^3 (21,000 and 27,000 ac-ft) of water annually for use in Salt Lake Valley (Hudson 1962:84). The most recent modification of flow in the Provo River was associated with the Deer Creek Reservoir, begun in 1938 and completed in 1941. The reservoir has a usable capacity of 189 × 10^6m^3 (153,000 ac-ft) (about one-half the average annual flow of the Provo River). The net seasonal effect on the Utah Lake area has been an increase of between 4.9 × 10^6 and 7.4 × 10^6m^3 (40,000 and 60,000 ac-ft) annually during the summer season (Hudson 1962:84–85).

The Spanish Fork River basin occupies the southeastern portion of Utah Valley and averages about 123 × 10^6m^3/yr (100,000 ac-ft) of flow under natural conditions. Additional water is diverted from the Colorado drainage basin via the Strawberry Reservoir system completed in 1915. Water from Strawberry Reservoir is diverted into the Diamond Fork River, a tributary of the Spanish Fork River. The average amount of water diverted into the Spanish Fork drainage has been approximately 86 × 10^6m^3/yr (70,000 ac-ft/yr), particularly during the months of June, July, and August (Hudson 1962:90–x3). The Central Utah Project of the Water and Power Resource Service (formerly the Bureau of Reclamation) completed enlargement of the Strawberry Reservoir in 1975, and additional water will be diverted in the future from the Colorado River Basin to the Great Basin via the Spanish Fork River.

Irrigation reservoirs have also been constructed on the headwaters of the Peteetneet Creek-Payson system, American Fork River, and other tributary streams entering Utah Lake. These reservoirs are much smaller than either Deer Creek or Strawberry and are used to regulate the flow of the streams for irrigation purposes. Through diverting water for irrigation, some of the streams entering Utah Lake are completely dry in late summer.

Use of water from Utah Lake proper for irrigation purposes is much less than that used from the streams entering the lake in Utah Valley. Historically attempts were made to utilize water from the lake for irrigation through use of pumping stations constructed on the west side of the lake where no perennial streams exist. One of the earliest of these projects was associated with the settlement of Mosida, which was developed on the southwest shore of Utah Lake by people from the Denver area from 1909 to 1917. This project consisted of pumping water from the lake with three pumps for irrigating 3845 ha (9500 ac) of land on the southeast shore of Utah Lake (Brough 1974:2–5). This was very successful initially as land was planted to orchards and irrigated, but the lowering of the lake's water level as the wet cycle passed left the intakes of the pumps above water and the project was abandoned. There are several small irrigation companies presently taking water from a pumping plant on the northeast shore to irrigate a small quantity of land.

One of the major factors affecting Utah Lake water is the "compromise" level of the lake. Irrigation interests in Salt Lake Valley wanted to use Utah Lake for storage of water for release to Salt Lake Valley in the late summer, but farms around Utah Lake became flooded with increased lake level. The first plan to raise the level of Utah Lake was in 1864, when it was proposed that a dam be placed at the head of the Jordan River to raise the level of Utah Lake four feet. The Provo City council objected to this action and the dam was not built (Jensen 1924:253–254). However, in the spring of 1879 the farmers of Salt Lake County began to build the proposed dam. By 1881 it was noted that high water in Utah Lake resulting from the completed dam was causing "fearful damage" to farms around the lake. Some farmers felt the best plan was to blow up the dam, but it was finally determined that the question would be submitted for arbitration between the two groups. In 1884 an agreement was reached that regulated the extent to which Salt Lake irrigation companies

could increase the level of the water in Utah Lake. The 1884 decision called for a 6-foot-wide opening in the bottom of said dam not to exceed 6 inches above the base of the existing dam, which represented the low watermark for the lake. Obstructions or diversions placed in this opening could not exceed 3 feet 3½ inches. The level of the lake when it was raised 3 feet 3½ inches was referred to as the compromise level (Jensen 1924:256–257). The difficulty of enforcing this agreement and the differing interpretations of where the low watermark was with reference to the compromise level resulted in additional suits. In 1895 additional adjudication was undertaken, and a new compromise level was reached 2 inches below the former one. This compromise level of 4,488.9 feet above sea level (later determined to be 4,489.34 feet) has been the shoreline since. It should be noted, however, that the actual shoreline fluctuates considerably because the opening in the dam at the head of the Jordan River during some spring high-flow periods will not allow the water to flow out rapidly enough to prevent an increase above this level—with resultant flooding of farm lands (Figure 6 shows lake fluctuation from 1920 to 1977).

Utah Lake continues to be a storage area for Salt Lake Valley irrigation, and the streams flowing into it remain a primary source of irrigation water for the lands around the lake. As of 1979, recent expansion of the Strawberry Reservoir with future increased flow in the Spanish Fork River during the summer, and proposals for a new reservoir in the Provo River drainage basin above Heber (Jordanelle Reservoir) will further affect the flow of the Provo River. The Bonneville unit of the Central Utah Project, of which the foregoing changes are a part, includes diking of the Provo Bay and Goshen Bay to further change the configuration and area of the lake proper (Central Utah Project, Bonneville Unit 1972).

Other than for irrigation and fishing, the use of Utah Lake and its streams has been varied. Water from the rivers has been and is used for culinary purposes, including an average of 31 × $10^6 m^3/yr$ (25,000 ac-ft/yr) for use in Salt Lake City through the Salt Lake aqueduct, the use of springs in Provo Canyon for Provo City, and use of the headwater source areas of the Peteetneet and Summit Creek areas for their respective communities. These uses are minor when compared to the total volume of water involved in irrigation, however.

The lake has historically been useful for other purposes. There was barge traffic on

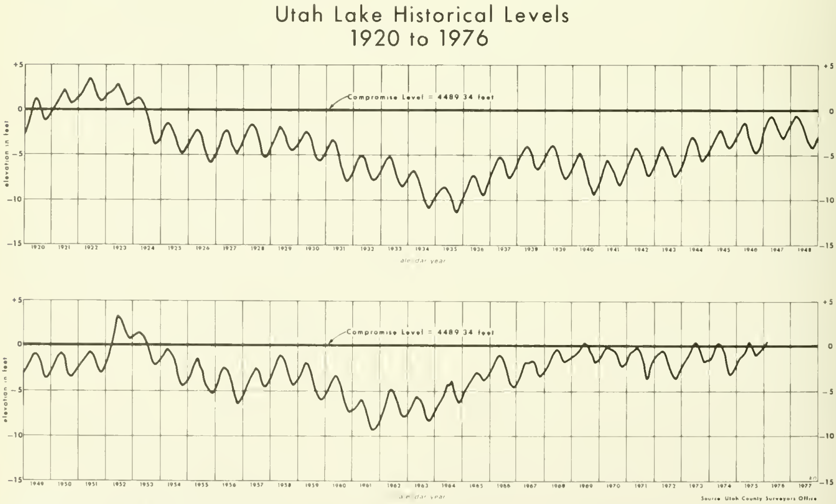

Fig. 6. Water levels in Utah Lake.

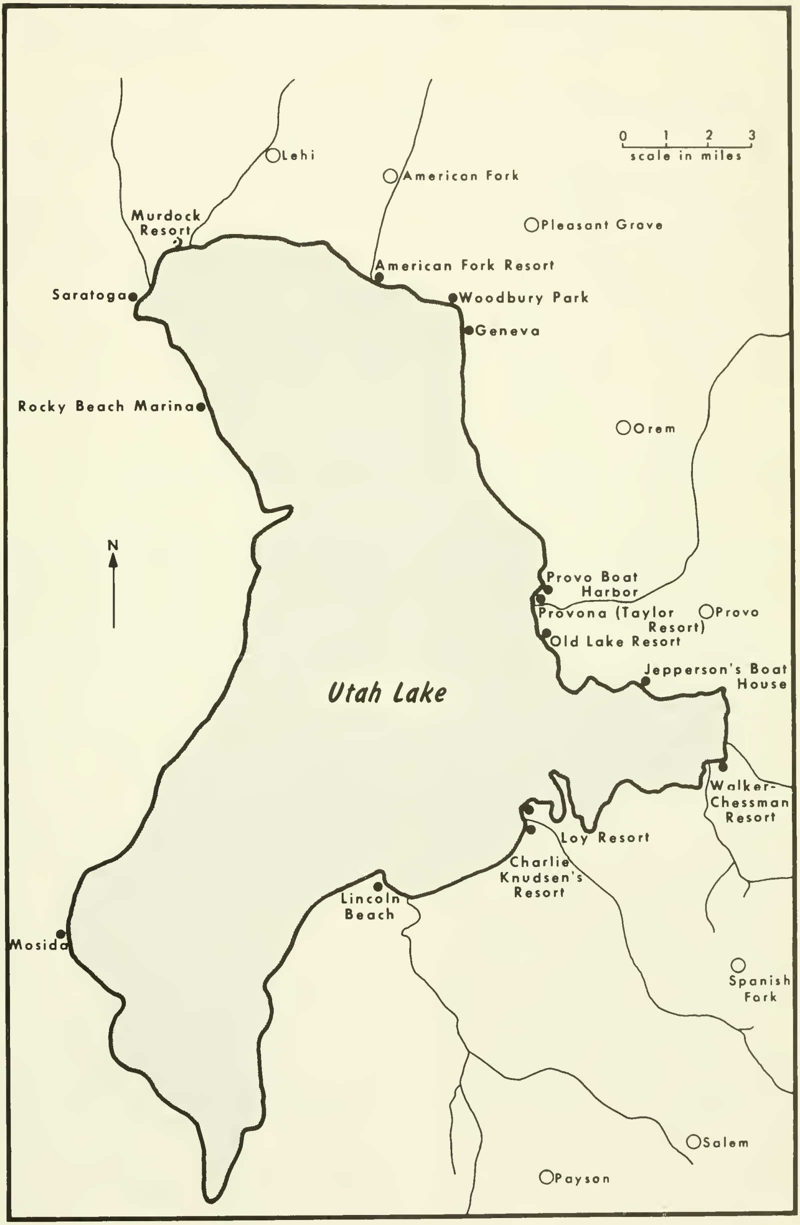

Fig. 7. Location of current and historical recreational facilities on Utah Lake.

TABLE 4. Resorts on Utah Lake from 1860 to the late 1930s

Saratoga	1860s to present	Baths, swimming pools, pavilions for dancing, picnicking
Walker-Chessman	1870s–early 1900s	Hotel, restaurant, boat rental
Woodbury Park	1880–1888	Summer cottage, bath houses, dance pavilion, boat dock
Old Lake Resort	1883–1907	Pavilion, boat house, ice house, restaurant, bath house, two piers
Geneva	1888–1935	Hotel, saloon, bath houses, pavilion, boat harbor
Lincoln Beach	1889–ca. 1900	Tourist house, swimming pool, store, saloon, dance pavilion
American Fork Resort	1892–1930s	Dance hall, pool hall, piers, picnic facilities, cafe, bath houses
Mindock Resort	1894–ca. 1900	Dance pavilion, picnic facilities, bath houses
Jepperson's Boat House	1890s–1920	Picnic facilities, piers, boat harbor, boat yard, refreshment stands
Knudsens' Resort	1913–ca. 1918	Boat rentals, fishing equipment rental, picnic facilities
Loy Resort	1913–1925	Boat rentals, picnic tables, bathing facilities
Provona (Taylor Resort)	1825–1930s	Store, dance hall, 30 cabins, bath houses, picnic facilities

Source: Glen R. Huber, "The Attitude of the People of Utah County Towards Utah Lake as a Recreational Site," Thesis, BYU, 1972, p. 27–35.

the lake between Provo and Mosida during the period of the town's existence from 1909–1917 (Brough 1974:8). Earlier proposals had suggested that towns on the south end of Utah Lake could be connected directly with Salt Lake City via a canal down the Jordan River and Utah Lake, but by 1863 these plans had been abandoned (Steele, p. 21). There were other schemes for using Utah Lake for transportation that were never implemented, except for one which would have connected the rich mining area of Tintic with Provo through use of a boat entitled the "Florence." Passengers and cargo were to be shuttled between the Tintic stage lines on the west side of the lake and the Denver and Rio Grande western railway at Provo. The boat made one trip in 1891 to meet the stagecoach but failed to make connections. The idea was abandoned before a successful commercial link could be completed. Other uses of the lake for boating were primarily of an excursion nature and consisted of boats for carrying people about the lake for sightseeing and dancing (Jensen 1924:267–268).

One of the major uses of Utah Lake has been for recreation. The Anglo settlers ranked recreation as the lake's third most important use. Figure 7 indicates the location of 15 resorts that have existed around the shore of the lake (Huber 1972:29). Table 4 provides information on the specific resorts that have been located around the lake. Subsequent to the time of the resorts the most important developments have been associated with the Provo boat harbor. The U.S. government assisted the city in its initial development in the early 1930s. It was maintained by Provo City and the Provo Boat Club until 1976, when it was turned over to the state. Since that time the boat harbor has been improved and now has facilities for camping, boating, and ice-skating. In addition, there are other private boat marinas around the lake, including the Rocky Beach Marina on the west side of the lake now utilized by a private boat club.

The potential for future development as a recreation and aesthetic resource is great. There is potential for enlarged sport as well as commercial fishing. The increasing population of the Utah Valley area means that it will continue to be a major recreational site. Proposals by the Department of the Interior for diking the lake will increase recreation opportunities, as well as provide additional irrigation water for the lands around the lake.

Utah Lake and its tributary streams were central to successful occupancy of the Utah

Valley region by white settlers as well as to earlier Indian occupants. For the foreseeable future, Utah Lake will continue to be of central importance to Utah Valley residents. An understanding of its fauna and flora, geology, setting, and use is essential in understanding its importance and maximizing its use.

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GEOLOGY OF UTAH LAKE: IMPLICATIONS FOR RESOURCE MANAGEMENT

Willis H. Brimhall[1] and Lavere B. Merritt[2]

ABSTRACT.— Utah Lake is a remnant of Lake Bonneville, from which it originated about 8,000 years ago. Analysis of sediment cores reveals significant variations in lake salinity and sedimentation rates. Notable examples are a very dry, high-salinity period between 5000 and 6000 years ago; a major freshening, wet period between 2700 and 3000 years ago; and a very dry, high-salinity period between 1400 and 2600 years ago. smaller variations are interspersed through the lake's history.

Long-term sedimentation rates are estimated at about 1 mm (0.039 in) per year in most of the lake, but post-colonization rates appear to be about 2 mm (0.079 in) per year. Faults in the lake appear to be lowering the lake bottom at about the same rate as sediment has been filling it. Bottom sediments consist of about 60 to 80 percent calcite in the lake proper, much of which precipitates from the lake water itself.

The lake-bed faults are similar in character to those of the Wasatch Fault that bound the valley and mountains a few miles to the east. Lake bottom springs and seeds are localized, in the most part, along the eastern and northern lake margins where all major tributaries occur and groundwater recharge is largest. Only limited spring activity appears to be associated with the faults.

In a geological sense, Utah is an old lake—shallow, turbid, and slightly saline—and has been since its "birth" with the demise of Lake Bonneville approximately 8,000 years ago.

Geologic History and Setting of Utah Lake

Utah Valley, of which Utah Lake occupies more than one-fourth, lies near the junction of three of the great physiographic provinces of North America. To the west stretches the Great Basin, a vast expanse of arid intermontane valleys extending from the Wasatch Mountains to the Sierra Nevadas. To the east lies the western portion of the Rocky Mountains, expressed in central Utah by the high peaks of the Wasatch Mountains rising above the Wasatch Fault, one of the largest of the fractures of the earth's crust in North America. Not far away to the southeast is the colorful Colorado Plateau Province. The rich and varied physiographic setting of the valley and its lake suggests that they are heirs of a rich and varied natural history, the principal part of which, for present purposes, is that associated with the past 30,000 years.

Utah Valley and its companions in the Great Basin were born in the aftermath of convulsions that seized the crust in central Utah some 70 million years ago as North America moved westward and collided with the lithosphere of the western Pacific Ocean. Huge sheets of sedimentary rock, crumpled in paroxysm, formed the ancestral Rocky Mountains of the region. Later, some 30 million years ago, the crumpled rocks began to be blocked into intermontane valleys by high-angle faults, one of the most famous of which is the Wasatch Fault that bounds Utah Valley on the east (Fig. 1). Recurrent movements on these faults continue to the present time, and thus maintain the intermontane basins in spite of erosion and infilling of sediments from the highlands.

The high-angle faults are the principal structures contributing to the intermontane physiography. Rock waste eroded from the rising mountains has been transported downward and deposited in the valleys. Probably sediment as thick as several thousand feet occupies the central portions of Utah Valley (Cook and Berg 1961); similar thicknesses of rock have been worn away from the ever-rising mountains. A dynamic equilibrium seems to have been maintained for some 30 million years between the uplifting of the

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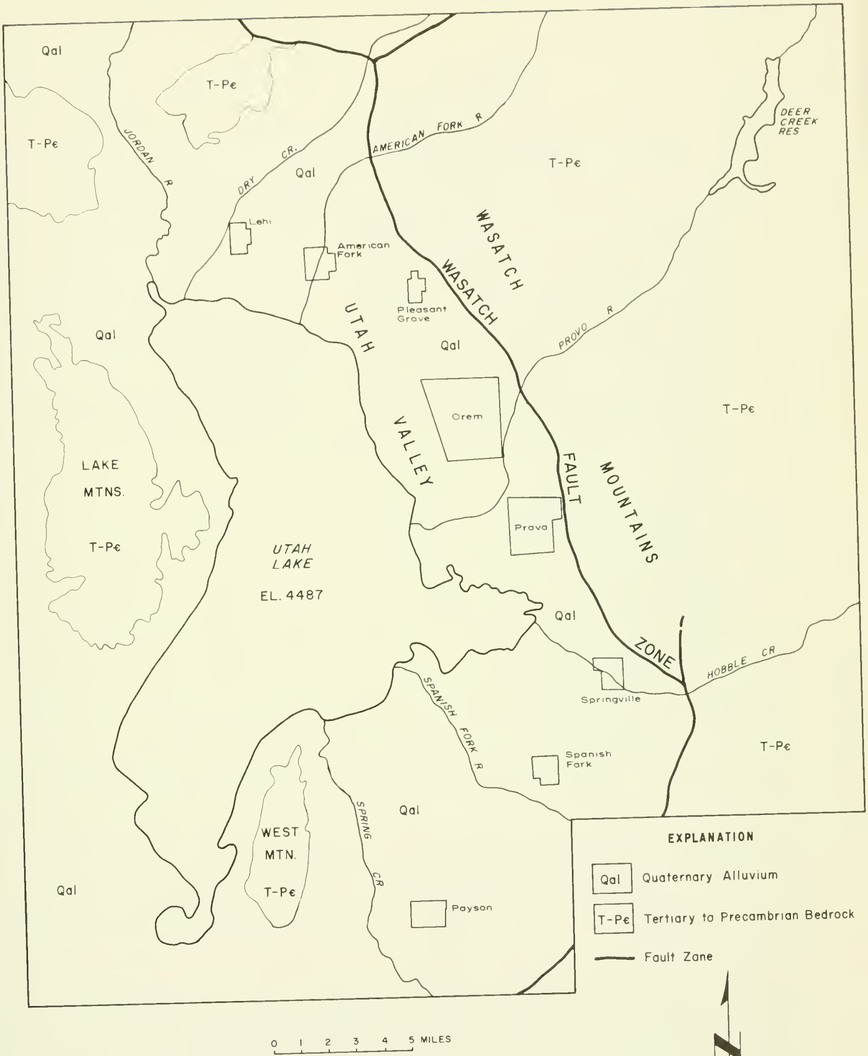

Fig. 1. A simplified geologic map of Utah Valley that shows the relationship of Utah Lake to its valley. The floor of the valley west of the Wasatch Fault is composed almost entirely of Quaternary Alluvium. The mountains east and west of Utah Lake are composed of bedrock ranging from Tertiary to Precambrian age. The Wasatch Fault marks the boundary between the two domains (modified from Stokes 1962).

mountains and the downdropping of the valley on the one hand, and of erosion and infilling on the other.

Lake Bonneville (Fig. 2), the ancestor of Utah Lake and the Great Salt Lake, occupied the intermontane basins to a greater or lesser

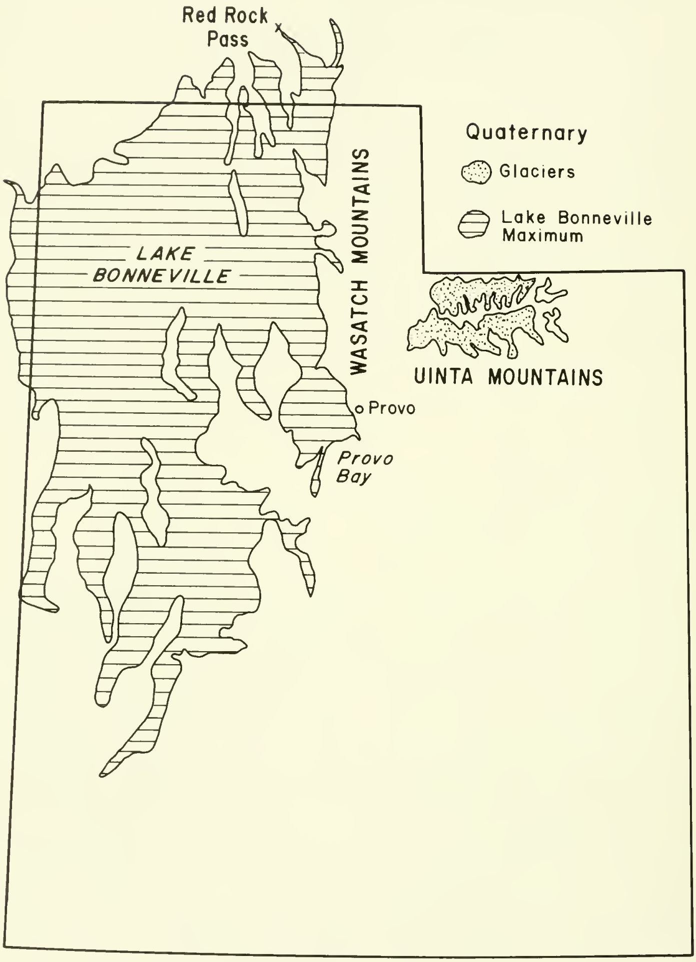

Fig. 2. The distribution of Lake Bonneville at its maximum size (adapted from Bissell 1968).

extent from about 75,000 years ago to about 8,000 years ago (Gilbert 1889, Bissell 1968). Lake Bonneville coincided in time with the Wisconsin stage of the Pleistocene Epoch; that is, with the last stage of the Great Ice Age that has so profoundly affected planet earth during the past one million years or so.

The size and depth of Lake Bonneville is recorded in the layers of sediments accumulated on its margins and floor. The lake was largest during times of cool, wet climates, smallest in times of warm, dry climates (Bissell 1968). The level and extent of the lake fluctuated through three principal levels, designated the Alpine, Bonneville, and Provo substages (Fig. 3). At its highest level, some 30,000 years ago, Lake Bonneville spilled over into the Snake River drainage at Red

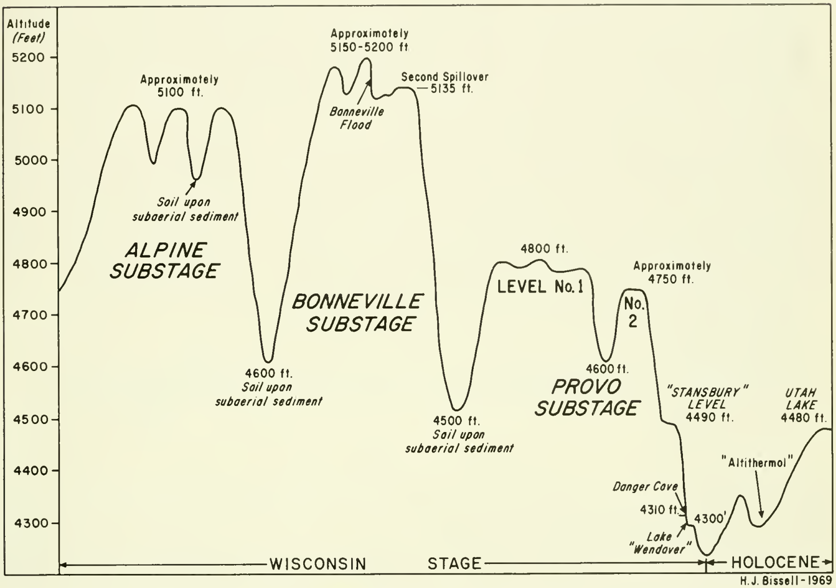

Fig. 3. Elevations associated with the principal substages and lesser fluctuations of Lake Bonneville. Lake Bonneville dried up and passed from existence at the end of the Wisconsin Stage, some 10,000 years ago. Utah Lake originated in the aftermath of Bonneville's passing and is associated with the Holocene Epoch, 10,000 years ago to the present (adapted from Bissell 1968).

Rock Pass near Preston, Idaho (Fig. 2), and quickly dropped from about 1585 m (5200 ft) above sea level to about 1463 m (4800 ft), where the lake stabilized at the Provo substage, with fluctuations, until about 8,000 years ago.

The relatively long period of Lake Bonneville's stability at the Provo substage led to the formation of some prominent benchlands, such as those at Orem, Mapleton, and Spanish Fork. These alluvial benchlands, formed where the rushing rivers met the lake, are among the most striking topographic features of Utah Valley.

The climates of North America generally became warmer and drier at the end of the Pleistocene (Great Ice Age) Epoch some 10,000 to 12,000 years ago. Ice sheets formerly occupying much of the northern portions of the continent began to retreat. In the Great Basin, Lake Bonneville passed from existence, and in the aftermath the Great Salt Lake and Utah Lake were formed.

Utah Lake, born and orphaned of Lake Bonneville, records its nearly 10,000 years of history in its sediments. Hansen (1934) was first to recognize that variations of sand, silt, clay, and plant remains, including wood, exposed in a test pit northwest of the mouth of Provo River, associate with strong changes of the level of the lake and of changes of climate in the region during the past few hundred to thousands of years. Hansen did not assign ages to the variations; the carbon 14 dating method was not available at the time.

Bolland (1974) collected a core sample, 500 cm (197 in) deep, at a point about 2.5 km (1.6 miles) west of Geneva in the late summer

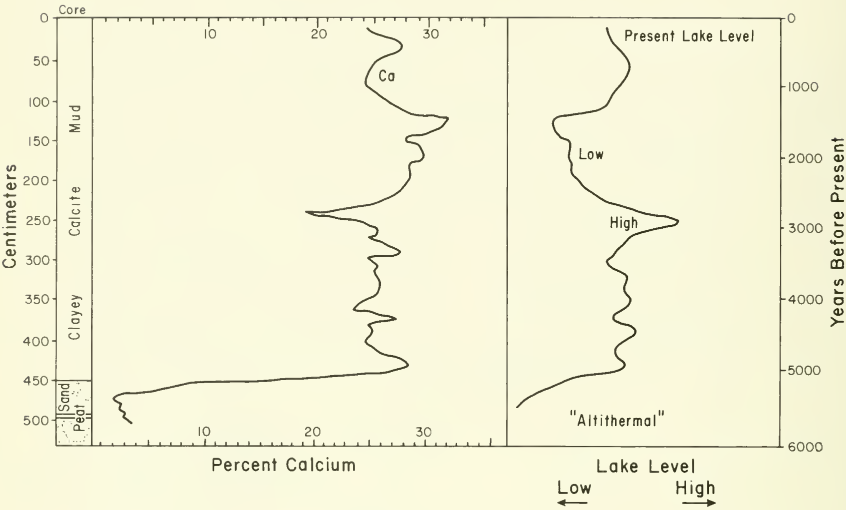

Fig. 4. Characteristics of a core sample of Utah Lake sediments collected approximately 2.5 km west of Geneva. High concentrations of calcium (calcite) are believed to associate with low levels of the lake as compared to recent levels. The sand and peat layers below 450 cm are believed to correlate with the altithermal, a time of extreme aridity described by Antevs (1948) (adapted from Brimhall 1973).

of 1970, to study the presettlement history of Utah Lake by means of sediment changes and variations in fossil diatoms. The core (Fig. 4) consisted of nearly uniform gray silt to a depth of 450 cm (175 in). Below that depth, to 510 cm (201 in), the core consisted of fine quartz sand with a small layer of peat at 490 cm (193 in). The change from silt to sand and to peat clearly indicates that at some time in the distant past, Utah Lake was much lower and smaller than at present, since the sand and peat must associate with an ancient shoreline that persisted over a considerable period of time. Bolland submitted a sample of the peat, weighing 1.8 grams (0.004 lb.), to Radiocarbon Ltd., Spring Valley, New York, for dating. The result was 11,400 ± 800 years.

Brimhall (1973) performed a chemical analysis of the major constituents of the core and assigned some time lines based on apparent inputs of iron from the steel plant, phosphorous from sewage, and other criteria, but evidence obtained during the summer of 1975 (Brimhall, Bassett, and Merritt 1976) make these data appear to be in error. We believe that the 11,400 ± 800-year-old dating of the peat layer is at least twice too large. Contamination of the sample with small amounts of detrital calcite could cause the result to be too high.

Based on data from the latter study, and reassignment of time lines in the core, it is presently believed that the sand layer at the bottom of the core correlates with a very dry period recognized in the Great Basin some 4,000 years ago (Antevs 1948). The beginnings of Utah Lake are believed to associate with sediments about 4 m deeper than the bottom of the core sample, as shown in the acoustical profile (Fig. 5). If this assignment is correct, as we believe, then approximately 8.5 m (28 feet) of sediment have accumulated since the beginning of Utah Lake. The average rate of accumulation of sediment is approximately 8.5 m (28 ft) in 10,000 years, or 0.00085 m (0.033 in) per year. Some questions still remain, however, as to the lake's sedimentation rate, and this value should still be regarded as tentative.

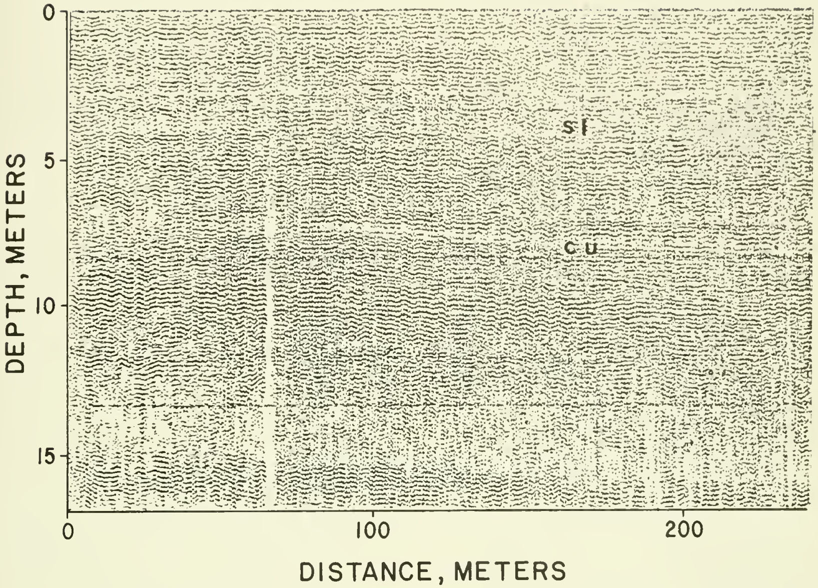

Fig. 5. Acoustical profile of sediments in the vicinity of the sample collected and analyzed by Bolland (1974) and Brimhall (1973). The reflection at about 4 m is believed to correlate with the sandy layer (sl) described by the above workers, and the second, stronger reflection at about 8.8 m is believed to correlate with the clay unit (cu) of the Provo Formation, deposited in the waning stages of Lake Bonneville.

Assuming a linear rate of deposition, the sand layer with its contained peat was deposited from 5300 to 6000 years ago during a long, dry period called the "altithermal" by Antevs (1948).

Variations of the calcium content of the cores between 18 and 32 percent (Fig. 4) are believed to associate with fluctuations of lake level caused by short-term wet and dry cycles of several years' duration, not as long as those associated with the sandy and peat layers. Rises in calcium content associate with decreased inflow during dry periods and contained large evaporation loss from the lake surface. An increased concentration of salts in the lake, including calcium and carbonate, and subsequent increased precipitation of calcite (calcium carbonate) occurs. Under natural conditions, lake level could vary at least 2 m (7 ft) since the flow rate in the outflowing Jordan River is a function of lake level. The lake level is a function of inflow, outflow, and evaporation over time.

Inspection of the calcium profile (Fig. 4) reveals some pronounced variations of concentration in the upper half of the core. Unusually high concentrations occur between 120 and 220 cm (47 and 87 in), and unusually low concentrations are present between 230 and 250 cm (90 and 98 in). Assuming that the high concentrations correlate with low lake level and size, and the low concentrations with high lake level and size, and assuming an average sedimentation rate of 0.85 mm/yr (0.033 in/yr), then the lake was small and shallow between 1400 and 2600 years ago, and larger and deeper between 2700 and 3000 years ago.

The profile also reveals that the level of the lake has fluctuated to a lesser extent than the above extremes during the past 1000 years. The sharp peak at about 25 cm (9.8 in) is believed to associate with a very dry period in the southwestern U.S. some years ago, based on tree ring data (Schulman 1956). It should be noted, however, that the upper 10

cm (3.9 inches) of the core sample was imperfectly obtained since the sediment-water interface was not sharply defined.

Reports have been made commonly in the news media in recent years that Utah Lake was a clear, blue lake in precolonization times, but the geological aspects of the lake as reflected in its sediments make the claim seem doubtful. Most of the reports by early settlers of the pristine quality of Utah Lake associate with diary accounts in which observers viewed Utah Lake from such distant points as Point-of-the-Mountain, or from nearshore localities where rivers emptied into the lake. Under these conditions, it is understandable that observers would conclude that the lake was clear. But the sediments in the lake, most of which were accumulated well before the coming of man into the valley, record that the lake has been a geologically old lake for a long time, stretching back to Lake Bonneville, and perhaps beyond. It is believed that geological factors are still the controlling factors in the lake, although human interaction and impact on the lake are important locally, particularly along the eastern shoreline.

Although Utah Lake has existed less than 10,000 years, a relatively short time in the span of geologic time, it is nevertheless an old lake from a geological point of view. The chief characteristic contributing to its senescence is its shallowness. At present, its average depth is about 2.8 m (9.2 ft) (Fig. 6), which contributes greatly to its turbidity, large evaporation losses, hence slightly saline waters, and warm summer temperatures, hence abundant communities of algae.

In summary, the geological setting and history of Utah Lake is rich and varied. The lake lies in one of the most scenic regions of North America. Climatic changes occurring in the region over the past 75,000 years, and especially the past 10,000 years, have been spectacular, for they range from very wet to very dry, and the record of these changes is preserved in the sediments of the lake as well as in other natural systems such as tree ring growth.

It is clear that these prehistoric changes occurred essentially independent of the influence of man. Natural forces still appear to dominate the lake as a whole although some man-caused influences are locally important. The potential exists, under the influence of continuing growth of populations in the surroundings, for man-made influences to dominate. Whatever the outcome in the future, the geological history of Utah Lake will continue to give a useful perspective on the management of the lake and its resources.

SEDIMENT CHARACTER AND TRENDS IN UTAH LAKE

Previous Work.— Bissell (1942) published a preliminarey report on the character of the sediments in Utah Lake. Sonerholm (1973) has described the broad outlines of the mineral compositions of the sediments of the lake and their distribution. Bingham (1975) has described the major trends of the particle sizes contained in the sediments and their distribution through the lake. Brimhall (1973) has studied the character of sediment in a core sample, 520 cm deep, to determine the broad outlines of the Holocene (recent) geologic history of the lake; and Brimhall et al. (1973) conducted a reconnaissance study of the sediments of Utah Lake, Holocene to upper Pleistocene age, by means of an acoustical profiler. The latter investigation yielded significant information, heretofore unavailable, on the character and distribution of deep-water springs and of the geologic faults in the lake floor, both of which are important to resource management.

Sediment Types.— Utah Lake is characterized as a carbonate-type lake because the principal constituent of its sediment is calcium carbonate, $CaCO_3$, whose mineral name is calcite. The compound as found in the lake is not pure, but carries small concentrations of magnesium, strontium, and other impurities. Quartz and other forms of silica are generally the next most abundant constituents, followed by clay minerals of the illite and montmorillonite and mixed layer types.

Locally, near the mouths of the major rivers joining the lake and near the existing shorelines where wave action is vigorous, quartz is concentrated in long, narrow ribbons of sand.

The shallowness of the lake intensifies the interaction of the water with sediment. During heavy storms the waves generated on the

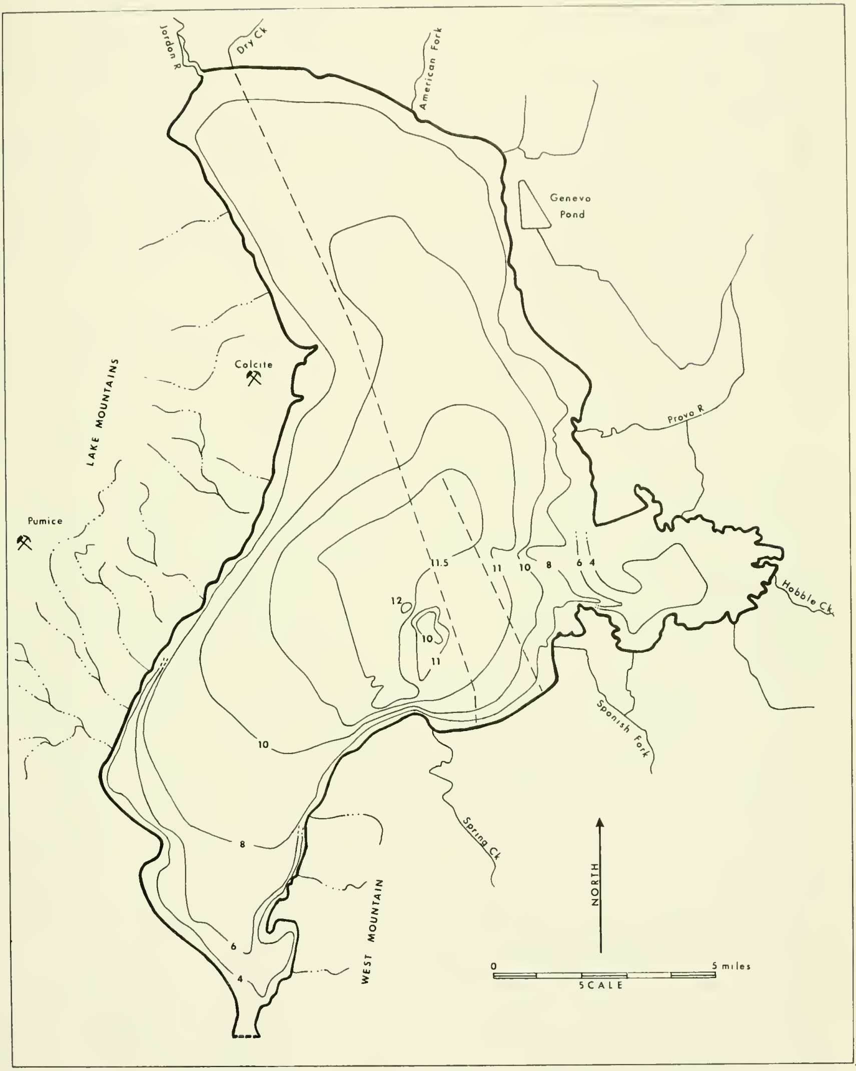

Fig. 6. Elevation contours of the floor of Utah Lake. The contours are given in feet below the level of the lake surface at 1367.94 m (4488 ft). Add 1.34 ft to the depths to reference them to compromise elevation (4489.34 ft) (adapted from Sonerholm 1973).

lake have sufficient amplitude to stir much of the lake floor, which contributes to the strong turbidity of the water, which in turn imparts the impression of pollution, although this turbidity results from a natural process. The sediment-water interface on the lake

floor is not generally sharply defined, but is gradational. Core samples collected during the summer of 1975 indicate that the transition zone from water to sediment is usually about 0.5 m (1.6 ft). The consistency of the sediment in the transition zone ranges from thin to thick soup. The upper margins of these sediments are frequently stirred by storms and by bottom-dwelling organisms. This is a leading factor in the turbidity (quality) of the water; and the condition is due, in the main, to natural rather than man-caused processes. Based on the character of sediment core samples and the configuration of the valley floor, it appears that this condition has existed throughout the life of the lake.

Distribution of Calcium Carbonate.— Sonerholm (1973) collected 140 samples of bottom sediment from localities spaced on a one-mile grid and analyzed them chemically to determine the composition of individual samples and the distribution of the elements throughout the lake. From these data, he determined the mineral constituents and trends for the lake as a whole. The contour map of calcite content ratio shown in Figure 7 is a statistical trend surface map that shows only the broad patterns present in the data.

Throughout most of the lake calcium carbonate exceeds 60 percent (dry weight) of the sediment. In two principal areas, the concentration exceeds 70 percent. The first and largest of these extends from the middle of the lake opposite Provo Boat Harbor to the western midportion of Goshen Bay. The second and smaller area lies in the northwestern portion of the lake between Pelican Point and Saratoga Springs. The pattern observed is easy to explain. Calcium is transported to the lake by surface waters and by subsurface waters. The valley and mountains surrounding the lake, and the sediment and bedrock beneath the lake are composed in the main of limestones and, to a large extent, sandstones, or combinations. Most of the calcium arrives in solution, but some arrives as particulate matter suspended in surface waters. Calcite is precipitated from lake water as evaporation increases the calcium and carbonate concentrations and by calcite depositing algae and other microorganisms abundantly present in the interior of the lake. The particles thus formed are tiny, ranging in the silt and clay size (from less than ⅛ mm to submicroscopic dimension). Such particles are too small to settle readily in the nearshore regions where wave action is vigorous. Consequently, they accumulate more in the central parts of the lake.

The unusually high concentration of calcite in the northwestern portion of the lake associates with thermal springs, striking faults (see later section of this paper), and with an unusually large concentration of organic matter in the sediments, presumably derived from higher biological activity in the area (Bingham 1975).

Distribution of Silica.— Silica, as used in this report, means any of the several forms of silicon dioxide present in the lake sediments. These may include quartz, SiO_2, or hydrated and/or amorphous forms of variable composition that may be associated with organisms such as diatoms that gather silica from water and sediment to form their shells.

Inasmuch as calcium carbonate generally exceeds 60 percent of the sediment, and silica comprises most of the remainder, the distribution of silica shows an inverse pattern to that of calcium carbonate; in short, the carbonate dilutes the silica. Silica ranges from near 50 percent of the dry weight of sediment in the nearshore regions to less than 15 percent in the regions occupied by high carbonate concentrations. Again, the pattern is not difficult to explain. Quartz is a hard, durable mineral, as are the other forms of silica, when compared to calcium carbonate. Moreover, the individual grain sizes tend to be larger than those associated with carbonate. These two factors, plus the input of quartz in sediment from the major rivers and wave action near shore, tends to deposit the silica in the near shore portions of the lake.

Distribution of Clay Minerals.— The term *clay* is used commonly in two different meanings, both of which are used in literature bearing on this report, so a clarification must be made as to the meaning of the term. Clay on the one hand refers to any natural inorganic substance whose constituent particles are less than 1/256 mm in size. Clay on the other hand refers to any of a family of mineral aluminosilicates whose constituent elements are structured in sheets and whose individual particulates are typically less than

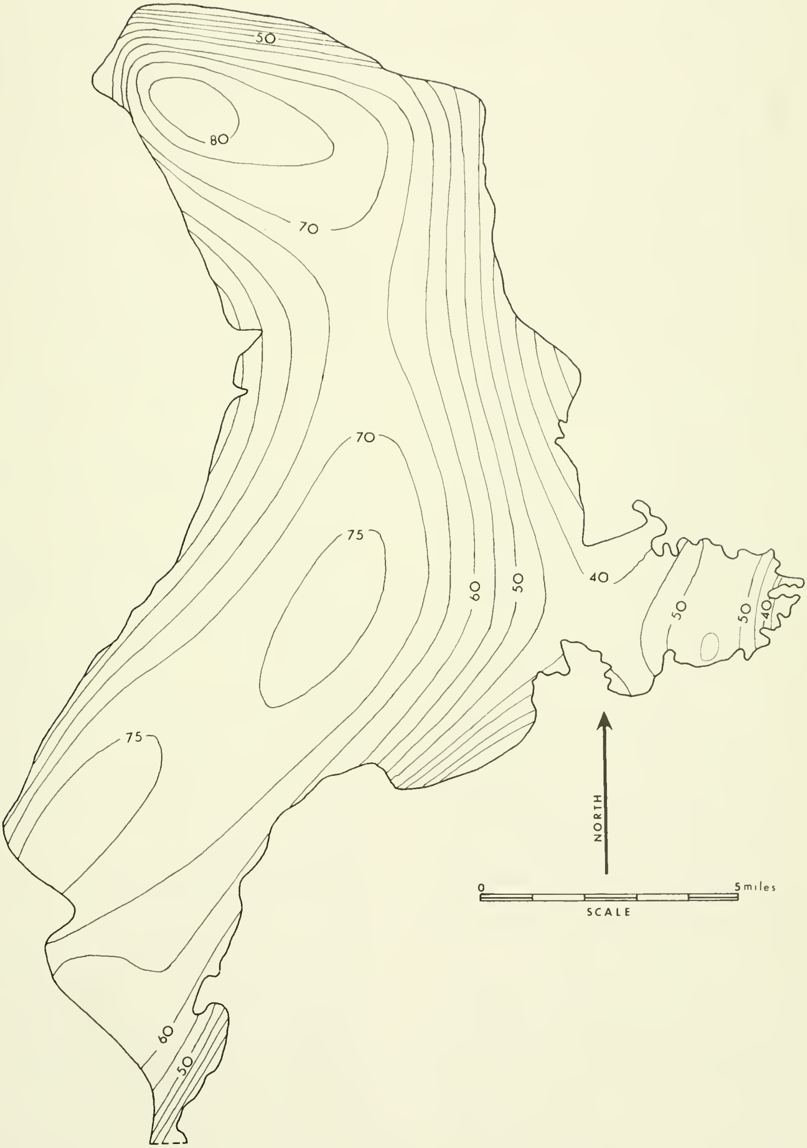

Fig. 7. Sixth degree trend surface map of calcite concentrations in Utah Lake sediments. Contours are in weight percent, dry sediment (adapted from Sonerholm 1973).

1/256 mm in size. In this paper, the term *clay* refers to the latter definition. The clay minerals of Utah Lake, ranging generally between 5 and 10 percent (dry weight), belong to the illite, montmorillonite, and mixed layer types.

The pattern of clay mineral distribution in Utah Lake is not easily defined because, among other things, it is a minor constituent diluted by carbonate and silica. Areas of high concentration, 9 percent or more, are located in the vicinity of the delta of the Spanish Fork River and near the mouths of the Provo and American Fork Rivers (Sonerholm 1973). It is clear that the source of the clay minerals is the detritus carried by the major rivers emptying into the lake. Longshore currents tend to disperse the clay minerals to the deeper waters adjacent to the shorelines.

Bingham (1975), studying the distribution of particle sizes of sediment, reports that most of the sediment of the interior of the lake is composed of particles in the silt and clay size range. He, of course, uses the term *clay* in the first of the senses described above. It is clear that much of Bingham's "clay" is in reality very fine-grained calcium carbonate.

Minor Constituents.— Minor constituents of the sediment of Utah Lake are numerous, but, in the main, they consist of calcium sulfate, probably as gypsum, iron oxides and/or sulfides, and organic material of varying kinds. Of course, water is a major constituent of the natural sediment. It ranges from a few percent to as much as 75 percent or more, depending on sediment type and location.

An area of relatively large organic concentration is present to the southeast of Saratoga Springs (Bingham 1975). Provo Bay carries a large concentration of organic material due to natural and man-caused biological activity. Powell and Benjamin sloughs also bear large concentrations of organic matter.

Summary Statement on Sediment-Community Relationships.— Bingham (1975) concludes that available evidence leads to the conclusion that plant communities of the lake do not associate with specific sediment types. Invertebrate animals, he says, tend to be more selective. Worms, midge flies, gastropods, bivalves, and ostracods prefer the carbonate muds of the open lake. Small crustaceans are found in the small, local exposures of tufa, hard rock deposits of calcium carbonate, in the vicinity of Bird Island and Lincoln Beach.

We believe that detailed studies will reveal stronger associations between sediment types and various plant and animal communities. The properties and distribution of sediments, in broad outline, have only been learned in the past few years. Much is presently being discovered concerning the plant and animal communities in the lake.

Sedimentation Rates.— Accumulation of one stratum upon another in sequence of time permits the calculation of an average rate of sedimentation when the absolute age of two different strata can be determined. In the instance of the core samples from Utah Lake, the uppermost stratum associates with the present time. The age of older, deeper layers may be determined by radiocarbon dating, by association with known geological or climatological events in the past, by introduction of components such as chemical contaminants or pollen grains from plants introduced by man, etc.

Sedimentation rates in geologically young lakes (deep and not subject to large sediment inflows) are typically a few tenths to a few hundredths of a millimeter per year. In Utah Lake, a shallow and geologically old lake, sedimentation rates are expected to be higher, probably near 1 mm per year, depending on the portion of the lake under consideration. Rates are likely to be highest in the vicinity of the mouths of the major rivers, and in the deeper parts of the basin where gravity pulls the soupy water-sediment mixture.

Acoustical profiling during the summer of 1975 (Brimhall, Bassett, and Merritt 1976) permitted the recognition at depth of a very persistent layer, the upper surface of which ranges between 8 and 15 m (26 and 49 ft) deep, and whose thickness appears to range between 5 and 10 m (16 and 33 ft). The stratum is believed to associate with a dark gray, silty clay found at that depth during exploratory drilling for the proposed Goshen Bay dike (U.S. Bureau of Reclamation 1964). The position and lithology of the stratum suggest that it is the clay unit of the Provo Formation (Hunt, Varnes and Thomas 1953, Bissell 1963), deposited in deep water some 10,000

years ago just before the demise of Lake Bonneville. If the assignment is substantially correct, and the age is likewise correct, the average sedimentation rate in the deeper portions of the lake ranges between 0.8 and 1.5 mm (0.031 and 0.059 in) per year. These values are consistent with rates observed in similar lakes, and with the known inputs of clastic and dissolved materials to the lake (Fuhriman et al. 1975).

The average sedimentation rate, 3.3 cm/yr (0.13 in/yr), calculated by Brimhall (1973) is now believed to be more than 10 times too large. Most of the data presented in that paper can be reconciled with the rates tentatively assigned above by reassigning the times given to the upper 25 cm (9.8 in) of sediment instead of the upper 250 cm (98 in). It must be emphasized that all these assignments are tentative, but the latest assignments are most consistent with new knowledge gained in 1975, and with comparison of Utah Lake with similar lakes. One of the most urgent problems associated with the lake is the matter of establishing its presettlement history by means of taking several core samples to 20 m (66 ft) deep to delineate that history. In the meantime, the sedimentation rates and history of the lake must remain known only within broad terms.

During the summer of 1975, 17 shallow core samples, ranging from 30 cm to 120 cm (12 to 47 in), were collected in various parts of the lake. Cores taken lakeward from the Geneva waste pond showed a mixture of cinder or slag with sand and lime silt. The relative proportions indicate an average sedimentation rate, for the natural components of the sediment, of about 5 mm (0.2 in) per year. Another core taken southeast of Saratoga Springs in organically rich sediment showed a high organic layer at a depth of 400 mm (15.7 in). Tentatively, this layer is assigned to a low level of the lake thought to exist about 400 years ago when drought conditions persisted over the region (Schulman 1956). If the assignment is correct, the average sedimentation rate at this locality, is about 1 mm (0.039 in) per year. Features in the other cores are not easily recognized, and so no additional information is available from them at this time.

Geologic Structures in Lake Sediments

Previous Work.— Two geologic maps of the bedrock and alluvial deposits in Utah Valley have been published. That of Hunt, Varnes, and Thomas (1953) describes the northern half of the valley, whereas that of Bissell (1963) describes the southern half. Neither of these maps show faults or geologic structures in the vicinity of Utah Lake or of the rest of the valley except for the Wasatch Fault at the base of the Wasatch Mountains. The absence of the structures from the maps does not mean these investigators concluded that none exist, but rather that erosional processes have made them unrecognizable.

The measurement and description of gravity anomalies in the vicinity of Utah Valley lead Cook and Berg (1961) to recognize the probable existence of faults in the floor of Utah Lake. Stokes (1962) plots three inferred faults extending in a general northwestward direction along the east side of Utah Valley. The first of these stretches between the east side of West Mountain to the vicinity of Saratoga Springs. The second, from Payson to the middle of Utah Lake, and the third, from the mouth of Spanish Fork Canyon to Orem, American Fork, and Lehi. Markland (1964) demonstrates the probable existence of a fault near Arrowhead Resort.

Cluff, Brogan, and Glass (1975) investigated the Wasatch Fault in Utah Valley with respect to land use planning. Cluff, Hintze, Brogan, and Glass (1975) have also investigated the Wasatch Fault in northwestern Utah as regards recent to current seismic activity and recent fault displacements in Pleistocene strata. Geomorphic evidence, as well as tree ring data, indicate that recent faults in the Wasatch Fault zone may be no older than a few hundred years.

Faults.— As an outgrowth of a reconnaissance study of the deep-water springs of Utah Lake by means of a sonarlike device (Brimhall et al. 1976), an unusual opportunity was afforded to study the faults and other geologic structures present in the strata underlying the lake to a depth of as much as 25 m (82 ft). The faults beneath the lake are sometimes remarkably displayed (Fig. 8) by the reflec-

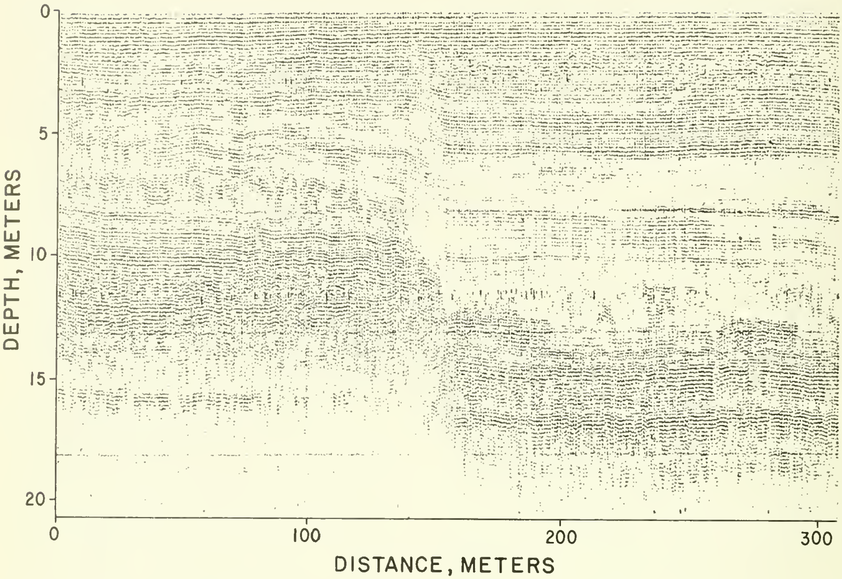

Fig. 8. The East Goshen Bay Fault, 2.4 km west of Lincoln Point. The top of the profile marks the present lake floor. The lower, dark layer on the left, whose top is 8 m below the floor, is offset on the right by about 5 m to a depth of 13 m. This stratum, a persistent marker stratum throughout the profiles, is believed to be the clay unit of the Provo Formation, uppermost Pleistocene age.

tion profiles obtained by sending pulses of sound waves into the lake floor and by recording the reflections, or "echoes" from the strata and structures beneath.

Heretofore, geologic structures of this kind, less than 10,000 years old (Pleistocene to Holocene age), have only been inferred to exist in the lake floor by extensions of faults observed in bedrock or alluvium in the lake surroundings, and by geophysical measurements such as gravity anomalies. Now, for the first time, the existence, character, and distribution of the faults in the lake floor have been observed. This section sets forth these findings and reports their significance as they apply to the history of Utah Valley and the management of the resources of the lake and its surroundings.

Three major faults (Fig. 9) are herewith designated as the Bird Island Fault, the East Goshen Bay Fault, and the West Goshen Bay Fault, which, along with several minor faults and a few folds, were discovered, mapped, and characterized by acoustical profiling in the summer of 1975. These structures exhibit characteristics that are consistent with faults mapped elsewhere in the valley by previous workers, and they add considerable detail to the knowledge of the structural geology of Utah Valley. The faults are furthermore of considerable interest as regards resource management, inasmuch as some of the major spring areas of the lake appear to be controlled to some degree by the distribution of faults in the lake floor.

Bird Island Fault.— Bird Island Fault (Fig. 9) extends northeastward from the eastern part of Goshen Bay to the west side of Bird Island. It then continues northward opposite the mouth of Provo River, and then passes slightly west of north to the vicinity of the mouth of the American Fork River. The western side of the fault is downthrown relative to the eastern side. Observed displacements (past 10,000 years) range from 2 m (66 ft) to less than 0.5 m (1.6 ft). Generally, the larger displacements occur at the extremities of the fault.

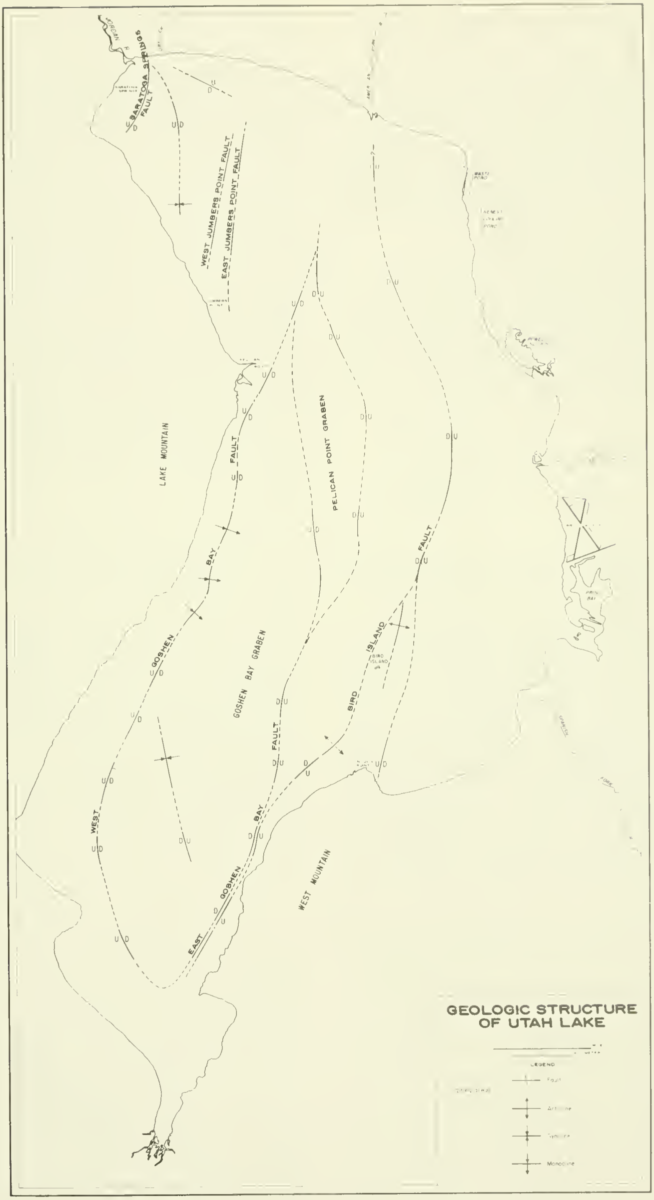

Fig. 9. The principal geologic structures present in the floor of Utah Lake, and the location of the presently known spring areas(adapted from Brimhall, Merritt, and Bassett 1976).

The eastern fork of the Bird Island Fault leaves the main fault and passes southward about 3 km (1.9 mi) north of Bird Island and is inferred to pass to the west of the Island toward the east side of West Mountain. The fault is clearly evident in the acoustical profiles just eastward of Lincoln Point. Since the eastern side of the fault is downthrown nearly 2 m (6.6 ft), it is clear that the block including West Mountain and Bird Island stands structurally high (horst).

One could be led to believe that the coincidence of the northern portion of the Bird Island Fault where thermal springs exist with a major spring zone on the eastern side of Utah Lake (Brimhall et al. 1976) accounts for the location of the springs, but we are of the opinion that the fault is at most only a contributing factor. Hydrologic and sedimentation factors are thought to be dominant because only a minority of the spring areas is shown to be directly associated with the fault.

East Goshen Bay Fault.— The East Goshen Bay Fault forks at a point about 2.5 km (1.6 m) west of Bird Island (Fig. 9). The main portion extends southward from the juncture to a position west of, and parallel to, the Bird Island Fault in the eastern section of Goshen Bay. Adjacent to West Mountain the two faults are in such close proximity that they may be expressions of a compound fault rather than two separate, distinct faults. Westward of Lincoln Point, the fault exhibits approximately 5 m (16 ft) of displacement. The western side of the fault is downthrown to form a portion of the Goshen Valley Graben.

From the juncture, the east fork of the East Goshen Bay Fault passes first northeastward then northwestward through the approximate midsection of the lake to a point about 5 km (3.1 mi) northeast of Pelican Point. The west fork of the fault passes northward of the juncture to the vicinity of Pelican Point, where it appears to rejoin its partner northeast of Pelican Point. The interior block bounded by the two forks of the fault is displaced downward relative to the other blocks; hence, the interior block is a graben designated as the Pelican Point Graben. It represents the lowest point of Utah Valley from a structural standpoint.

Displacements of the faults bounding the graben range from about 1 m (3.3 ft) to less than 0.5 m (1.6 ft). The larger displacements are found on the southern side of the graben. In general, the displacements are smaller than those associated with the Bird Island Fault.

The section of the lake occupied by the Pelican Point Graben appears to have very little spring activity associated with it (Brimhall et al. 1976). Spring activity along other portions of the fault likewise appear to be slight.

West Goshen Bay Fault.— The West Goshen Bay Fault extends from the southern portion fo Goshen Bay, where it may converge with and join the East Goshen Bay Fault (Fig. 9), to the vicinity of Pelican Point, where it appears to join the east and west branches of the East Goshen Bay Fault. The eastern side of the fault is displaced downward, which makes the block bounded by West Goshen Bay Fault and its partner to the east a graben, designated as the Goshen Bay Graben. Displacements on the fault range from approximately 2 m (6.6 ft) to less than 0.5 m (1.6 ft). Southward of Pelican Point 5 or 6 km (3.1 or 3.7 mi), the fault is replaced by a monocline that dips gently to the east.

The reconnaissance study of Brimhall et al (1976) shows that spring activity along the fault is very weakly expressed.

Minor faults.— The East and West Jumbers Point Faults, though minor faults in terms of length, exhibit some of the most spectacular displacements to be found in the lake. Figure 10 shows the acoustical profile obtained over the northern portion of the West Jumbers Point Fault. A similar fault is displayed on the southern section of the East Jumbers Point Fault. Displacements on the faults ranged from about 5 m to about 1 m (16 to 3.3 ft). The eastern blocks are displaced downward relative to the western. The unusual offsets on these faults indicate that the section of the lake occupied by these faults is active tectonically. The only other fault to compare is the East Goshen Bay Fault just west of Lincoln Point (Fig. 8).

None of these faults, as observed in profile, exhibited spring activity at the several points transected, although it is entirely reasonable

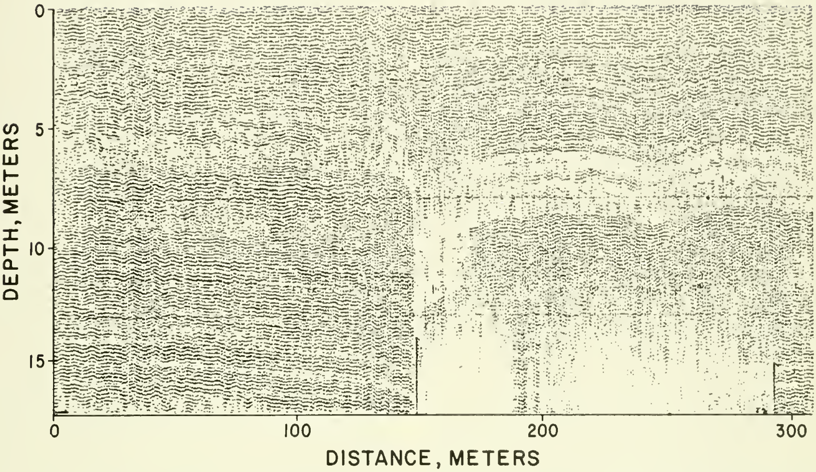

Fig. 10. A spectacular fault on the north end of West Jumbers Point Fault. The right-hand, eastern block is displaced downward about 2.5 m. The lower dark layer, between 7 and 9 m on the left side, is believed to be the clay unit of the Provo Formation.

to suppose that there are springs at places along the faults.

Another small fault, named the Saratoga Springs Fault, lies about 1 km (0.6 mi) east of Saratoga Springs Resort. The eastern side of the fault is displaced downward approximately 1 m (3.3 ft) as seen in profile. Almost certainly, some spring activity is associated with the fault, but such activity was not deterined conclusively in the acoustical profile transects.

Deep-water Springs of Utah Lake

During the summer of 1975, a 23-transect reconnaisance study of Utah Lake was made by means of a sonarlike device (Brimhall et al. 1976). It was possible to infer spring and seep areas from the profiles. The distribution of the areas containing springs is shown in Figure 9.

Inspection of Figure 9 reveals that less than 10 percent of the floor of Utah Lake is associated with springs or seeps. Most are located in a zone 1 to 3 km (0.6 to 1.9 mi) from shore on the eastern and northern portions of the lake.

The reason for such a distribution is clear when it is realized that the principal watersheds contributing to the lake occur in the eastern and northeastern zones. The springs/seeps occur in response to availability of water, to the thinning and wedging of permeable, water-bearing strata in a lakeward direction, to the thickening of fine-grained strata to confine the trapped water in a lakeward direction, and to the development of a hydraulic pressure by the aquifers sloping toward the interior of the lake. Thus, the springs/seeps occur principally as the result of prevailing sedimentary and hydrologic conditions.

Occasionally the springs/seeps are clearly controlled by faults, but in general, the pattern is weak. The northern extension of the Bird Island Fault coincides with the concentration of springs/seeps along the eastern side of the lake, but the fault in this section is weak in that its displacement is typically less than 0.5 m (1.6 ft) and the springs/seeps are widely scattered on opposite sides of the fault.

It is noteworthy that the faults showing the greatest displacements, the Jumbers Points

Faults and the East Goshen Bay Fault west of Lincoln Point, associate only slightly, if at all, with springs. If a strong association were present, the investigation during the summer of 1975 would have revealed it.

Three separate attempts were made in late August 1975 to sample water from springs previously located by the acoustical profiler, but the results were inconclusive. Vertical profiles, made with a portable Hydrolab water quality probe, showed no significant variation in conductivity from the surface of the lake to the inferred mouth of the spring/seep areas at three different localities investigated. The quality of water and the quantity of water being discharged from the deep-water springs is still unknown, and awaits further investigation.

Implications for Resource Management

The geology of the lake includes its geologic history and setting, physiography, drainages, groundwater patterns, sediments and strata, and geologic structures (faults). These form a physical base upon which the plant and animal communities, including those of man, live and adapt, and they form the principal boundary conditions, subject to change by interaction, that impose upon the management of the resources of the lake.

The following items summarize some principal implications for resource management imposed by geological conditions known at the present time.

The Life of the Basin.— A significant question regarding Utah Lake is: How fast is the lake basin filling up? What is the expected life of the basin as presently constituted and operated? Available geological data indicate a rate of filling at about 1 mm (0.039 in) per year over the past 10,000 years, although the rate has likely more than doubled with the settlement and urbanization of Utah Valley. It is equally clear, however, from the character of the faults present in the lake floor, that the valley is deepening relative to the mountains at the same time it is receiving sediment. The displacement on the faults indicate an approximately equality of deepening and infilling, or an approximate state of dynamic equilibrium existing between deepening of the basin by the faults and the infilling of the basin by transport and deposition of sediment derived from the surroundings. This trend is consistent with the overall geologic history of the region that has been characterized by recurrent movements on the Wasatch Fault since its origin some 30 million years ago. So the depth of the lake, relative to the elevation of the present shoreline, will probably remain constant for the foreseeable future. This does not mean, however, that the resources of the lake could not be improved by artificially deepening the water.

Faults crossing proposed Goshen Bay dike.— Although a proposed Goshen Bay Dike will cross some faults and folds, we do not believe they pose a serious threat to the safety or operation of a dike. Displacements would likely be no more than a few tens of centimeters, and probably much less, unless an earthquake of catastrophic proportions were to strike the area. Small displacements, if they occur, can be repaired quickly.

The geological condition of the lake.— A point commonly, almost pervasively, misunderstood by laymen and many experts as well, is that Utah Lake is a senile lake in the geological sense. It is a very shallow lake. It has a very large surface compared to volume. It is characterized by high evaporation rates. It is characterized by high rates of sedimentation. The exchange of impurities between water and sediment is likewise large.

Many mistakenly believe that the lake can be restored to a pristine state characterized by the waters of the mountain lakes of the region. The essential point missed is that Utah Lake cannot be returned to that condition. The natural history recorded in the sediment cores and profiles show that the lake has been in much the same as its present condition for centuries. This natural evidence opposes statements purportedly derived from diaries and journals of early settlers and observers that the lake was characterized by clear, blue water. Careful analysis of the conditions under which such observations were made indicates that most of them were made from some distant point such as the Point-of-the-Mountain where, even today, the lake has a clear, blue aspect, especially when incident light from the sun bears a critical angle just after sunrise or just before sunset. Reports of clear water and sandy beaches were made

mostly in the vicinity of the Provo River or other river inflows where the wide plume of clear water extended away into the lake. Under most of the conditions in which such observations were made, the water would have a clear aspect.

The character and conditions of observations, both from eyewitness accounts and from the natural record left in the sediments of the lake can be reconciled to the effect that the lake is and has been geologically old since its inception, with the water being turbid but sometimes appearing clear locally or completely, depending on the vantage point and conditions under which the lake was observed.

The foregoing should not be construed to mean that there have been no significant changes in the clarity of water in Utah Lake with the changes of level occurring over the past few thousand years; it simply means that the lake has not been a completely clear lake, in the same sense that many mountain lakes are clear, throughout most, if not all, of their histories.

Sediment character and distribution.— Research completed since 1973 has delineated the broad patterns of composition and grain size distribution of minerals being deposited on the lake floor. In all but the nearshore regions, the areas close to the mouths of the major rivers, and in the vicinity of Bird Island, calcium carbonate exceeds 60 weight percent. Silica and clay comprise most of the rest. In the same regions occupied by the calcium carbonate, the grain sizes are mostly and about equally in the silt and clay sizes, between 1/16 and 1/256 mm, and less than 1/256 mm, respectively. In the near-shore portions of the lake, silica in the form of sand is the most abundant constituent. Particle sizes are dominantly in the range between 1/16 and 2 mm.

We believe that these relationships have a larger bearing on the character of the plant and animal communities than previously realized, principally by reason of the lack of detailed study necessary to establish the relationships. Mapping of the lithologies of the near-shore regions and the related plant and animal communities is presently being done in a Water and Power Resources Services environment assessment study associated with proposed diking of Provo and Goshen Bays.

Geologic faults in the lake.— The geologic faults discovered and mapped in the floor of the lake during the summer of 1975 pose the same kind of threat that other faults pose in the valley, but none beyond those customarily assigned. That they exist and are consistent in character and distribution with the Wasatch and other faults bordering the valley is interesting and informative.

The faults exhibit displacements up to 5 m (16 ft) during the past 10,000 years or so, but it is unlikely that such displacements were achieved as the result of a single event. It is conceivable that the floor of the lake could be violently heaved by an earthquake, and that large lake waves could be produced, but, even if such did occur, the damage to the shorelines would probably be incidental to the damage wrought elsewhere in the valley by ground vibrations and movements.

The location and character of springs in the floor of the lake is more determined by existing hydrologic and sedimentation factors than by faults. The faults do appear to contribute substantially in a few places, however. In the event of strong earthquakes in the valley, it is not anticipated that the effect on springs in the lake floor would be large.

Acknowledgments

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HYDROLOGY AND WATER QUALITY OF UTAH LAKE

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Abstract.— This paper summarizes hydrological and water quality findings from investigations by the authors and their colleagues over the past 10 years.

Water and salt balances on Utah Lake for the July 1970 to July 1973 period show both evaporation (342,077 ac-ft/yr) and groundwater (114,355 ac-ft/yr) to be somewhat larger than previously estimated by others.

The lake is eutrophic, turbid, and slightly saline, as might be expected in a shallow, basin-bottom lake in a semiarid area. Overall water quality in the lake is fair to good and appears to be controlled more by natural factors than by the activities of man. An increase in total dissolved solids (TDS) from about 300 mg/l in major surface and shallow groundwater inflows to about 900 mg/l in the main lake is the most significant water quality change. Of this TDS increase, about one-half results from evaporation of about one-half of the total inflowing water, one-quarter from salts carried by mineralized deep-spring inflows, and the remaining one-quarter from the poorer quality surface inflows to the lake.

Calcium carbonate (calcite) precipitation from the lake waters accounts for about 40 percent of the estimated 0.85 mm/yr (0.033 in/yr) long-term rate of sediment buildup of the lake bottom. This precipitated calcite is postulated to be an important turbidity source in the wave-stirred lake.

This paper presents information on the overall hydrologic features of Utah Lake, including the results of an intensive study of its water balance during the July 1970 to July 1973 period; it also presents information on the chemical and microbiological quality of both inflowing waters and the lake itself.

Utah Lake is a shallow lake with an average depth of 2.8 m (9.2 ft) at compromise water surface elevation of 1368.35 m (4489.34 ft) MSL. Its depth is very uniform more than 1 km (0.6 mile) offshore. At compromise level, in approximate percentages, 80 percent is deeper than 2.5 m (8.2 ft) but only 20 percent is deeper than 3.5 m (11.5 ft). Maximum depths of about 4.2 m (13.8 ft) occur in the south central portion of the lake west of Bird Island. Figure 1 gives area and volume of the lake as a function of surface water elevation.

When the shallow character of the lake is combined with the semiarid climate of the area, a large net evaporation loss occurs from the lake. The main impact of this evaporation is an appreciable increase in the concentration of total dissolved solids (TDS) in the remaining lake water. This evaporation impact is compounded by a large TDS load carried by mineralized springs that occur in the lake bed and near-shoreline areas. The resulting TDS concentration of some 900 mg/l in the lake proper is two to four times higher than the average TDS concentrations of most surface tributaries and groundwater inflows. TDS concentrations vary considerably both spatially and temporally with the temporal variation occurring both seasonally and with longer wet and dry hydrologic cycles. These longer cycles may result in a severalfold increase in TDS during drought cycles as com pared to wet cycles.

Background on Water Balance Methodology

The hydrology of a lake refers basically to identification and quantification of all elements of lake inflow and outflow—an accounting for all waters that enter and leave a lake. In a general sense, not relating to any particular lake, the inflows are all surface drainage (including drains, seeps, surface wash, intermittent inflows, well-defined tributaries, etc.), groundwater inflows (including seepage from saturated shoreline areas sometimes referred to as inflow from bank storage), and direct precipitation on the lake surface. The outflows include surface

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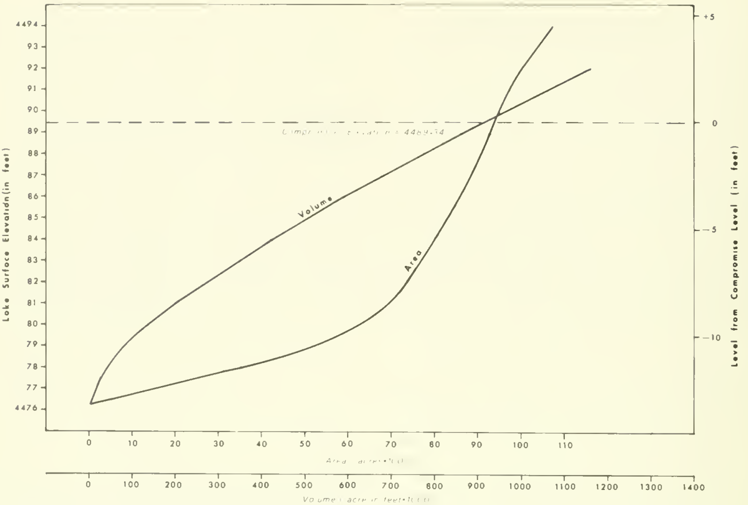

Fig. 1. Utah Lake area/volume curves as a function of elevation.

tributaries, groundwater seepage (including seepage into shoreline areas sometimes referred to as outflow to bank storage), evaporation from the lake surface, and transpiration from any vegetation growing in the lake.

The water balance is often stated as follows:

$$I_t + I_g + P - O_t - E = S \tag{1}$$

in which I_t = the volume of water in all inflowing tributaries;

I_g = the volume of all inflowing groundwater;

P = the volume of precipitation on the lake surface;

O_t = the volume of water in all outflowing tributaries;

E = the volume of water evaporated from the lake surface; and

S = the volume of water represented by the rise or fall of the lake level;

or in other words, the difference between all inflows and outflows must be equal to the change in lake storage, which may be readily determined from lake level records. Since evaporation is difficult to measure accurately in the field, it is often calculated from the inflow-outflow equation. This calculation is referred to as a determination of evaporation by the water balance method.

UTAH LAKE WATER BALANCE STUDIES

Fuhriman et al. (1975) reported on Utah Lake water balance studies made over the period of July 1970 to July 1973. This section summarizes the key elements of that study, including refinements in those analyses and results that are first published herein.

The objective of the water balance studies was to provide an accurate determination of the evaporation from the lake by the use of equation 1. Previous studies by others on Utah Lake have not had sufficient data to make accurate water balance calculations on a monthly basis.[3] Intensive measurements of tributary inflow and increased coverage of precipitation during the 1970–73 period made it possible to make computations on a monthly basis during the April through October period, when evaporation was greatest and when evaporation pan data were also available.

[3]The studies reported herein make use of the water balance equation on a monthly basis except during the winter months—November through March—when factors such as freezing of the lake water introduce other variables into the relationship. Evaporation calculations by the water balance equation are, therefore, reported monthly from April through October and then one five-month period—November through March.

Water Balance Factors

Some hydrologic measurements relating to Utah Lake have been made on a continuing basis for many years. Others have been made intermittently, and some have been measured intensively over relatively short intervals of a few months or a few years in connection with particular studies. A discussion of measurements made and/or utilized in the analyses reported herein are described in the sections that follow.

Surface Inflow.— A total of 51 surface water inflows have been identified as contributing to the lake on a regular basis. The location and identification of these tributaries are given in Figure 2 and Table 1. Of these, two are measured on a continuous basis by the U.S. Geological Survey at points near to the lake—the Provo River and the Spanish Fork River. A few inflows are measured on a continuing basis by private or governmental units. During the late spring in 1970, measurement stations were established on tributaries where none existed and measurements were taken at one- to two-week intervals.

In spite of careful identification and measurement of the surface tributaries, there are times—such as during the spring thaw or during heavy precipitation on the lands immediately surrounding the lake—when it is not possible to measure all surface inflow. These inflows must be estimated.

Inflow quantities for all tributaries were measured and tabulated on a monthly basis for a two-year period. Measurements of the larger tributaries were continued for a third year, with the less significant tributary flows being estimated during the third year. A summary of the surface inflow measurements over the three-year period was reported by Fuhriman et al. (1975). These figures, with some minor adjustments that have resulted from refinements in the earlier evaluations, are given in Table 2.

Lake Outflow.—Surface outflows are continuously measured by the Jordan River commissioner. Records of these outflows—consisting of the Jordan River flow, the Utah and Salt Lake Canal, East Jordan Canal, the Utah Lake Distributing Company Canal, and the LDS Church Elberta Farm Pumping—were

TABLE 1. Utah Lake tributaries: identification codes and sampling points.

Station	Stream	MAG 208 stream code	Location
UT 01 & 02	Drain	Zu 01-00.10 & Zu 02-00.10	Combined UT 01 & UT 02—measured 100 yds below confluence, E side of Saratoga Rd at 6800 N
UT 03	Dry Creek	DRCL-00.31	0.10 mi E of jct of 9550 W and 7350 N
UT 04	Drain	Zu 04-00.29	0.20 mi E of jct of 9150 W and 7350 N at 9" flume
UT 05	Drain	Zu 05-00.38	Approx. 200 ft W of jct of 8730 W and 7350 N at 9" flume
UT 06	Drain	Zu 06-00.38	Approx. 50 ft S of jct of 8350 W and 7350 N at 12" flume
UT 07	Drain	Zu 07-00.43	At jct of 8000 W and 7350 N at 9" flume
UT 08	Lehi Sewage Treatment Plant and Drain	LEW 0-00.90	50 yds E of jct of 7800 W and 7550 N—approx 15 yds downstream from road. Includes effluents from Lehi WWTP.
UT 09	Mill Pond	SPCL 01.10	At jct of diversion works at 7400 W and 7750 N
UT 10	Drain	Zu 10-00.50	1.25 mi S of jct of 6500 W and 7750 N at small diversion gate. Includes effluents from American Fork WWTP.
UT 11	American Fork Sewage Treatment Plant	AFWT	About 0.55 mi S of jct of 6500 W and 7750 N

Table 1 continued.

Station	Stream	MAG 208 stream code	Location
UT 12	Drain	Zu 12-00.95	0.2 mi W and 1.0 mi S of jct of 100 W and 400 S at free-fall
UT 13	American Fork River	AMFR-0.90	0.75 mi N of American Fork Boat Harbor on 100 W at 9' wide concrete appurtenance
UT 14	Drain	Zu 14-00.38	0.1 mi W of jct of 6400 N and 5750 W
UT 15	Drain	Zu 15-00.59	0.1 mi E of jct of 6400 N and 5750 W
UT 16	Drain	Zu 16-00.40	0.25 mi S of jct of 6400 N and 5300 W at exit from 1' culvert
UT 17	Drain	Zu 17-00.80	0.25 mi W and 0.15 mi S of jct of 4850 W and 6400 N at bridge over concrete ditch
UT 18	Geneva Cannery Drain	LINH-00.38	15 yds S of jct of 4250 W and 5600 N at culvert under 4250 W. Includes effluents from Pleasant Grove WWTP.
UT 19	Drain	Zu 19-00.15	0.15 mi N of Geneva effluents recording station on W Geneva Road
UT 20	Geneva Steel Drain	Zu 20-00.14	Geneva Steel effluents recording station
UT 21	Drain	Zu 21-00.14	0.2 mi S of Geneva effluents recording station on W Geneva Road
UT 22	Drain	Zu 22-00.14	0.5 mi S of Geneva effluents recording station on W Geneva Road
UT 23	Drain	Zu 23-00.10	At 9" flume on drain 0.9 mi S of Geneva effluents recording station on W Geneva Road
UT 24	Drain	Zu 24-00.10	1.3 mi S of Geneva effluents recording station on W Geneva Road
UT 25	Drain	Zu 25-00.09	At 9" flume, 30 yds S of dirt road at jct of 4000 N and W Geneva Road
UT 26	Orem Sewage Treatment Plant	ORWT	S of WWTP at 2500 W and 1000 S
UT 27	Powell Slough	POWS-00.75	At 5' culverts at S end of slough on dike road. Includes effluents from Orem WWTP.
UT 28	Drain	Zu 28-00.10	On N Boat Harbor Drive, 1 mi W of jct of Geneva Road and N Boat Harbor Drive
UT 29	Provo River	PROR-02.82	At USGS gaging station 1300 ft W of bridge on W Geneva Road
UT 30	Drain	Zu 30-00.33	Discontinued—jct of 3110 W and 550 S
UT 31	Little Dry Creek	Zu 31-00.68	0.1 mi W and 0.25 mi S of jct of 560 S and 2470 W
UT 32	Drain	Zu 32-00.28	0.25 mi S and 250 ft W of jct of 1600 W and 1150 S
UT 33	Flowing Well	Zu 33-00.01	0.5 mi S of jct 1600 W and 1150 S and approx 50 ft N of culvert at Big Dry Creek near steel standpipe

Table 1 continued.

Station	Stream	MAG 208 stream code	Location
UT 34	Big Dry Creek	BDRC-01.52	0.5 mi S of jct of 1600 W and 1150 S
UT 35	11th West ditch	Zu 35-00.95	At jct of 1100 W and 1560 S on south side of road
UT 36	5th West ditch	Zu 36-00.85	0.5 mi S of jct of 1560 S and 500 W
UT 37	University ditch	Zu 37-00.50	0.25 mi S-SW in interchange of 1420 S and University Avenue
UT 38	Mill Race	MLCR 02.34	0.35 mi S of 350 E and 1500 S. Includes effluents from Provo WWTP.
UT 39	Provo Sewage Treatment Plant	PRWT	350 E and 1500 S
UT 40	Drain	Zu 40-00.25	Discontinued—S of Provo WWTP 0.35 mi and 0.27 mi E
UT 41	Rat Farm Drain	Zu 41-00.25	S of Provo WWTP 0.35 mi and 0.3 mi E—about 100 yds S of road near metal-fenced enclosure
UT 42	Steel Mill Drain	Zu 42-01.00	0.81 mi N of 2400 S and 1050 E (near Kuhni Packing Plant)
UT 43	Spring Creek	SPCS 01.51	0.3 mi N of 2400 S and 1050 E (0.55 mi S of Kuhni Packing Plant)
UT 44	Hobble Creek	HOBC 05.46	0.25 mi S of 2400 S and 0.15 mi W of frontage road at 21' weir. Includes effluents from Springville WWTP.
UT 45	Packard Drain	Zu 45-01.44	On frontage road 0.85 mi N or 3900 S, 5 yds downstream from culvert under highway
UT 46	Drain	Zu 46-02.18	0.35 mi W of freeway on 3900 S
UT 47	Dry Creek	DRCS-02.46	0.85 mi W of freeway on 4000 S at 9' wide gate. Includes effluents from Spanish Fork WWTP.
UT 48	Spanish Fork River	SPRF 01.30	At bridge 3.7 mi W of freeway on Hwy 79. Gaged at USGS station 2.5 mi N of Lake Shore (USGS moved 1979).
UT 48A	East Branch of Spanish Fork River		3.4 mi W of freeway on 4000 S at culvert under road
UT 49	Drain	Zu 49-01.89	At jct of Palmyra Drive and 3200 W (.8 mi N of 5200 S and 3200 W)
UT 50	Drain	Zu 50-01.14	At jct of 4000 W and 5200 S
UT 51	Benjamin Slough	BENS-02.94	0.2 mi E of jct 6000 W and 6400 S at bridge over slough. Includes effluents from Salem and Payson WWTPs.
UT 52	White Lake	WTLK-01.50	Goshen Bay channel—near 3' flume approx ¼ mi NW of White Lake on outlet channel to Goshen Bay
UT 53	Jordan River	JORR-48.45	At bridge on Hwy U-121, 2.3 mi SW of jct with Hwy 73

Italicized stations are "major" tributaries; these are defined as those generally carrying more than 2000 acre-feet of flow each year.

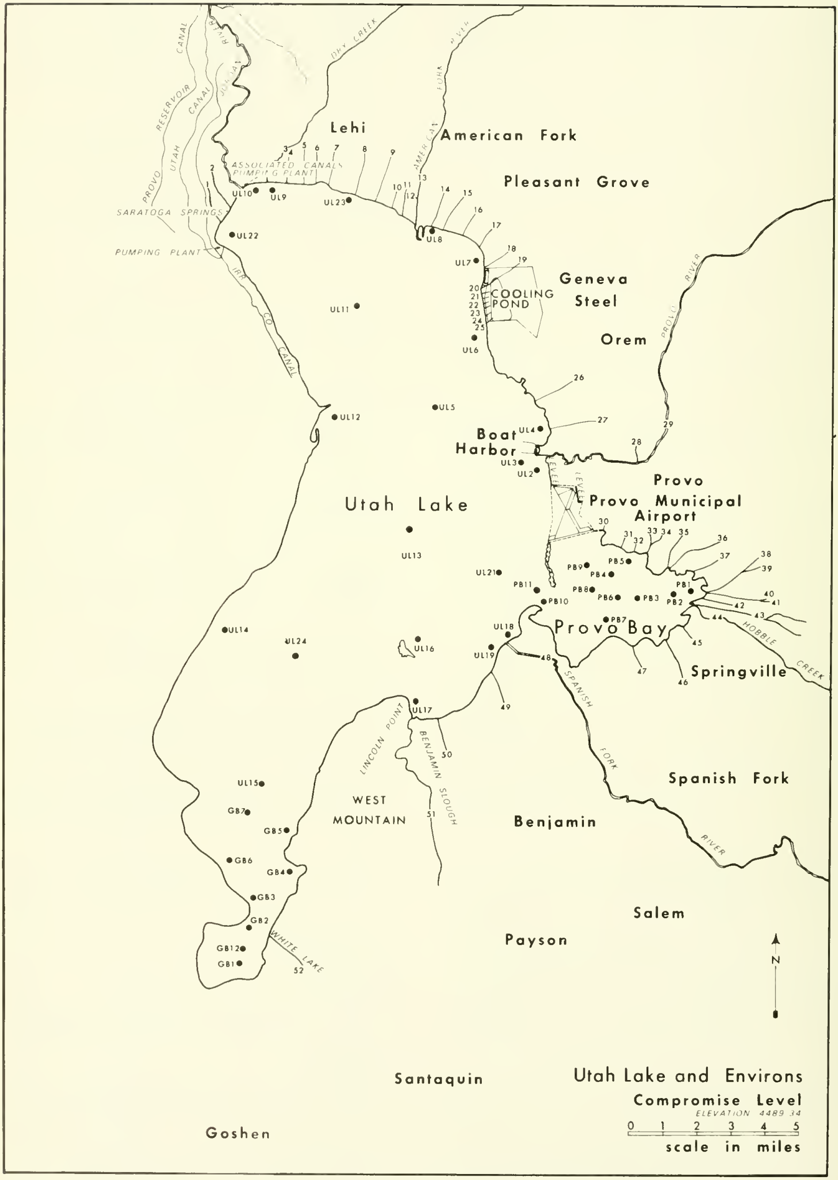

Fig. 2. Location and code numbers for Utah Lake sampling sites and code numbers of surface tributaries.

TABLE 2. Utah Lake surface tributary inflows, 1970–71 (all figures are in acre-feet of water, 1 acre-foot equals 1233.6 m^3).

Tributary number	1970 Jul	Aug	Sep	Oct	Nov	Dec	1971 Jan	Feb	Mar	Apr	May	Jun	Totals Jul–Jun
1	44	33	57	26	0	0	0	0	0	17	16	3	196
2	46	25	24	45	0	0	0	0	0	0	2	19	161
3	0	0	0	0	0	0	0	0	0	7	59	37	103
4	24	28	23	32	30	33	33	33	34	32	34	35	371
5	23	13	37	7	20	16	21	30	14	18	23	67	289
6	138	126	234	69	55	67	73	66	64	73	104	146	1215
7	43	62	37	40	29	34	75	47	40	81	102	65	655
8	353	117	385	436	376	383	404	314	274	316	327	392	4077
9	1287	678	1240	1507	1642	1474	1519	1189	1207	1066	977	1363	15149
10	207	236	275	262	213	185	191	175	181	185	240	269	2619
11	163	129	95	83	74	74	74	76	80	80	117	215	1260
12	64	58	99	80	61	54	60	47	35	61	136	154	909
13	58	67	45	52	44	26	23	21	23	25	49	501	934
14	148	163	153	155	126	109	120	102	109	128	125	226	1664
15	157	156	153	195	174	155	156	138	156	163	191	189	1983
16	143	73	118	119	99	93	111	111	122	124	146	152	1411
17	401	255	356	319	222	156	158	131	159	235	368	472	3232
18	1444	1569	2686	2442	2081	1866	2115	1725	1819	1974	1673	1519	22913
19	1	3	0	0	0	0	0	0	0	0	0	0	4
20	1842	2027	1849	1910	2170	2165	2196	1741	1910	2006	1910	1805	23531
21	0	0	0	0	0	0	0	0	0	0	0	0	0
22	0	0	0	0	0	8	8	6	6	4	2	0	34
23	0	0	0	0	4	6	6	6	6	6	5	2	41
24	12	8	11	17	20	19	22	17	16	15	13	13	183
25	67	98	58	59	82	94	119	88	85	23	72	89	934
26	314	313	289	252	296	217	202	199	225	217	252	260	3036
27	1210	1270	1240	1380	1440	1420	1500	1480	1540	1450	1530	1320	16780
28	7	0	28	35	68	67	182	129	79	87	47	28	757
29	1250	633	1220	9500	20700	23350	19280	17170	13310	18800	11690	19500	156403
31	78	121	164	149	177	160	116	106	119	143	118	66	1517
32	49	44	44	45	42	43	43	39	43	46	47	55	540
33	6	6	6	7	7	7	7	7	6	6	6	6	77
34	743	722	717	669	595	410	337	269	296	358	394	702	6212
35	91	92	199	118	149	132	93	99	45	65	82	75	1241
36	32	64	138	50	26	13	40	130	25	38	76	88	720
37	74	84	94	93	82	63	58	54	58	75	83	72	890
38	867	870	814	1041	1118	1041	990	898	1208	1031	814	825	11517
39	1524	1564	1361	812	948	928	935	828	853	1014	1182	1342	13291
40	232	229	185	247	236	208	184	166	184	167	170	148	2356
41	408	423	416	337	263	273	292	298	346	378	498	461	4393
42	1484	1403	1362	1708	1782	1568	1602	1390	1228	1274	1858	1297	17956
43	743	373	359	278	293	404	673	634	817	923	921	729	7147
44	145	128	758	1366	2002	2049	1979	1834	2178	2731	2012	557	17739
45	170	205	207	226	242	229	209	213	183	140	154	281	2459
46	494	577	422	267	176	217	178	164	178	194	227	523	3617
47	334	924	1134	1361	1211	1291	1211	1158	1215	1159	399	791	12188
48	453	681	2165	4130	5320	5810	6810	6810	9970	13860	10760	1910	68579
49	68	69	56	57	50	34	32	42	44	37	35	58	582
50	261	331	256	288	245	272	303	368	242	277	395	434	3672
51	1454	1645	3242	3454	3944	3885	3516	3706	3933	4233	2881	2159	38052
52	0	0	0	0	800	200	538	931	720	354	338	70	3951
UTI[a]									3000	2000	1000	1000	1000
TOTALS	19056	18695	24811	35725	49734	51308	48794	45185	48385	57696	44661	42490	486540

[a]UTI denotes unmeasured tributary inflow.

Table 2 continued.

Tributary number	1971 Jul	Aug	Sep	Oct	Nov	Dec	1972 Jan	Feb	Mar	Apr	May	Jun	Totals Jul–Jun
1	0	4	15	10	0	0	0	0	0	0	25	8	62
2	0	5	23	0	0	0	0	0	0	0	68	1	97
3	0	0	0	0	0	0	0	0	49	0	0	60	109
4	38	35	22	26	31	32	31	35	30	23	33	39	375
5	22	2	19	15	29	0	37	21	17	12	20	32	226
6	159	115	215	63	64	70	74	63	55	60	112	146	1196
7	68	79	135	194	191	97	92	58	30	57	179	74	1254
8	276	93	298	328	343	310	295	230	178	214	406	351	3322
9	1387	997	1445	1558	1418	1311	1291	1104	1168	916	375	1154	14124
10	215	207	220	217	204	180	178	16	213	274	325	233	2482
11	259	141	107	76	74	77	70	66	70	92	104	164	1300
12	73	96	121	114	90	72	49	38	50	100	168	178	1149
13	63	60	58	57	58	60	61	58	68	83	105	173	904
14	158	231	167	159	133	114	105	89	86	121	149	168	1680
15	123	106	158	178	163	151	129	115	121	135	150	177	1706
16	99	103	98	115	98	94	80	71	90	83	121	114	1166
17	348	377	428	378	249	171	141	123	117	179	375	506	3392
18	1374	1678	2693	2466	2020	1863	1654	1377	1353	1452	1150	1410	20490
19	1	3	0	0	0	0	0	0	0	6	0	0	10
20	1933	1980	2538	2266	2289	2440	2753	2377	2541	2509	2440	2313	28349
21	0	0	0	0	0	0	0	0	0	0	0	0	0
22	0	0	0	0	6	6	6	6	12	30	6	0	72
23	0	0	0	0	6	6	6	6	7	7	6	1	45
24	10	13	11	16	21	18	16	15	16	15	15	13	179
25	107	90	45	66	82	103	92	73	61	54	100	78	951
26	262	292	273	245	226	279	290	257	265	266	312	312	3279
27	1210	1270	1240	1380	1440	1420	1500	1480	1540	1450	1530	1320	16780
28	17	3	50	75	122	123	111	104	80	12	55	23	775
29	850	877	1120	15802	20229	20205	16520	16228	20577	16854	16723	29437	175482
31	104	100	149	137	105	109	123	104	74	89	68	65	1227
32	42	45	40	42	39	42	43	40	49	42	80	125	629
33	3	6	6	6	6	6	7	7	7	7	8	8	77
34	617	354	297	470	242	224	234	224	289	321	301	321	3894
35	46	54	119	211	214	133	148	35	80	125	141	119	1425
36	25	24	60	58	26	30	31	23	25	71	25	24	422
37	75	80	92	95	76	55	49	35	37	60	68	69	791
38	859	947	711	883	868	923	959	892	1008	726	750	684	10210
39	1439	1624	1401	1259	1117	1055	952	944	1128	1141	1325	1466	14851
40	404	255	273	206	169	149	123	29	31	30	18	0	1687
41	313	262	241	245	228	208	215	196	246	303	240	250	2947
42	1529	2057	2116	2241	1940	1468	1279	1294	1457	1743	2060	2338	21522
43	451	414	438	476	468	509	553	506	553	553	584	779	6284
44	149	191	434	1461	1663	1766	168	1818	2226	2130	92	161	14059
45	341	279	331	424	643	401	357	276	283	315	240	268	4158
46	386	456	274	216	203	191	185	127	178	202	240	292	2950
47	489	835	891	941	1073	823	935	1041	1992	1095	689	238	11042
48	593	538	1700	5343	6389	7289	7329	7525	10320	6926	801	736	55489
49	62	54	39	45	44	40	31	35	37	54	49	48	538
50	333	250	207	180	137	135	172	150	160	184	394	303	2605
51	1042	1156	2559	3063	3793	4013	4034	3664	3419	2600	1636	2172	33152
52	0	0	0	0	200	300	314	713	680	300	90	0	2597
UTI	0	0	0	0	0	8000	0	0	0	0	0	0	8000
TOTALS	18355	18838	23877	43806	49229	57071	45592	43748	53073	44021	34951	48951	481512

Table 2 continued.

Tributary number	1972 Jul	Aug	Sep	Oct	Nov	Dec	1973 Jan	Feb	Mar	Apr	May	Jun	Totals Jul–Jun
9	1537	1168	1309	1875	1666	1722	1506	1722	1968	1785	1107	1368	18733
11	129	124	138	143	130	135	143	130	130	140	150	150	1642
18	1599	1568	2410	2767	2350	1875	1783	1805	2029	1577	1844	1785	23392
20	1745	2372	2313	2593	2602	2579	2782	2250	2271	2063	2265	2405	28240
26	314	314	304	295	285	295	295	266	333	313	285	304	3603
27	1210	1270	1240	1380	1440	1420	1500	1480	1540	1450	1530	1320	16780
29	1840	732	2020	11400	13850	14090	16290	16000	17130	20680	41880	19470	175382
34	679	710	533	429	235	191	188	204	334	502	875	1154	6034
38	813	695	632	943	683	1185	1319	1206	1395	1325	678	546	11420
39	1475	1427	1381	1269	933	1135	1009	945	1094	1068	1465	1427	14628
41	286	455	550	524	529	336	240	272	340	374	460	387	4753
42	1020	1072	775	1161	1651	740	526	461	1055	1104	1423	1214	12202
43	861	829	439	689	455	252	144	218	375	371	383	980	5996
47	85	221	416	1072	1133	1156	1128	1137	1270	1187	893	119	9817
48	113	149	762	4950	6320	6450	6550	5730	7300	17090	40150	3480	99044
51	440	336	857	2413	2657	2619	2828	3307	3590	3273	3951	2023	28294
52	0	0	0	500	600	700	1200	1200	700	500	250	35	5685
UT1	3721	3416	4331	4929	5134	5278	8900	16700[a]	10912	8153	36779	17304	125557
TOTALS	17867	16858	20410	39332	42653	42158	48331	55033	53766	62955	136368	55471	591202

[a]In February abnormal winter thaw caused considerable unmeasured runoff.

obtained from Commissioner Brad Gardner. Outflows were tabulated on a monthly basis.

Precipitation.— Precipitation on the lake represents inflow to the lake. Precipitation from July 1970 through April 1971 was measured at the regular U.S. Weather Bureau stations at Provo (KOVO Radio Station), Pleasant Grove, Lehi, Geneva Steel Company, Payson, and Elberta. Beginning in the month of April 1971, additional measuring stations were established at Pelican Point, Dixon Farms, Lakeshore, and Provo airport. The areal distribution of precipitation on the lake surface was determined by using the Thiessen method of weighted distribution. Total lake surface precipitation was tabulated on a monthly basis.

Change in Storage.— Calculation of water balance elements on a monthly basis requires determination of storage volume at the end of each month. A lake water stage recorder is maintained and operated by the Jordan River Commissioner. The water level charts indicate that wind can cause considerable fluctuation—more than 0.6 m (2 ft) at times—in the water level of the lake. Carefully analyzing wind-caused seiches and averaging high and low water levels during such oscillations allowed correction to an accurate end-of-month lake stage.

Ground Water Inflow and Outflow

The geology of Utah Valley (Hunt, Varnes, and Thomas 1953, Bissell 1963) is such that the area surrounding Utah Lake—and the lake itself—is underlain with low-pressure artesian aquifers. In addition, the water table in the unconsolidated shallow deposits near the lake almost always has a gradient toward the lake. Under these conditions, there is obviously groundwater inflow to the lake from a number of different geologic formations. Based on geologic characteristics of Utah Valley, groundwater outflow from the lake is felt to be negligible.

Springs in the Lake.— It has long been known that a number of springs flow directly into the lake from its bed. Evidences of extensive spring flows into the lake have been noted by Swendsen (1905), Richardson (1906), Hunt et al. (1953), Bissell (1963), and Mundorff (1970, 1971), who wrote of the existence of such springs and of the general geologic features of the lake that caused the springs.

Several attempts have been made to measure the flow of the springs. Harding (1941) made observations over a period of several years and also accumulated information obtained from interviews with others relating to

springs in the lake. Viers (1964) made detailed studies of lake springs in an attempt to determine their effect on the lake's chemical quality; he made observations from the air and ground to locate spring areas and then sampled them for quality determinations. He located and identified 30 separate springs in the lake. Milligan et al. (1966) made careful observations, including a number of measurements of both quantity and quality, of the nearshore springs flowing into the lake. Hansen (1975) reports observations of many springs above the water line during the 1934–35 drought, when the lake was at its lowest historical level. Dustin and Merritt (1980) considered the hydrogeology of the lake with emphasis on Goshen Bay and concluded that between 12.3 and 22.2 × $10^6 m^3/yr$ (10,000 to 18,000 ac-ft/yr) of groundwater is coming from Cedar Valley into the southern end of the lake.

There are many springs in the lake, but it is obvious that field measurement of this source of inflow is virtually impossible. Since it was necessary to input this element as a known quantity in the water balance equation, an indirect method quantifying this inflow was used to supplement the limited amount of spring flow data available. This method was the use of salt balances as described later.

Evaporation

Measurements of evaporation from a U.S. Weather Bureau Class A evaporation pan have been made during the summer months at the Utah Lake pumping station southwest of Lehi for 28 years. The record of these measurements is published in the monthly *Climatological Data for Utah*, published by the U.S. Weather Service.

However, evaporation from standard pans is different than evaporation from nearby lakes themselves, and the degree of difference depends upon many factors. In fact, accurate determination of evaporation from a lake is a very difficult problem since some elements of inflow and outflow are almost impossible to measure accurately.

The most intensive study of evaporation from a lake surface ever undertaken was conducted at Lake Hefner, Oklahoma, in 1950 and 1951. Harbeck et al. (1952, 1954) reported results of this intensive evaporation study involving many emminent scientists and engineers. Many detailed measurements and evaluation methods were used to determine the evaporation from this carefully selected lake. Prior to this study, lake evaporation was generally estimated by multiplying the pan evaporation by a coefficient that usually was between 0.7 and 0.8. These values were based mainly on work by Rohwer (1931), Harding (1935), and Young (1947).

A number of publications reporting on extended Lake Hefner investigations have been issued. Harbeck (1962) wrote on the use of the mass-transfer theory. Kohler et al. (1955) and Kohler and Parmele (1967) reported on studies using evaporation pans and meteorological factors such as solar radiation, air and water temperature, and dew point temperature to develop charts that might be used at other locations to estimate evaporation. Extending these studies to specific locations in the U.S., Kohler et al. (1959) published generalized maps for the U.S. to provide a basis for evaporation estimates. These maps are based upon empirically derived charts utilizing the meteorological factors mentioned above.

The results of measurements at Lake Hefner reported by Harbeck et al. (1952) showed clearly that the average pan coefficients for the Class A evaporation pans varied from month to month. Neglecting one month, in which there was apparently some sort of observation error, the coefficients ranged from about 0.4 to 1.32. The low values occurred in the spring of the year when the lake water temperature was lower than the pan water temperature, and the high values occurred in late summer and fall when the reverse was true.

Previous evaporation studies on Utah Lake.— Various studies in the past have resulted in estimates of evaporation from Utah Lake. Swendsen (1904) reported use of an evaporation pan at Lehi as early as 1901 in studies by the Salt Lake City engineer to estimate Utah Lake evaporation. Jacobsen and Peterson (1932) reported on studies that included evaporation estimates. Harding (1940) analyzed the available evaporation pan records near Utah Lake over the period 1903 to 1936 to develop estimates of evaporation

from the lake. He used a constant value of 0.70 for a pan coefficient and then used the Lehi record, extending it by various statistical comparisons with other records.

In connection with the development of a water resources management simulation model for the Upper Jordan River drainage area, Wang et al. (1973) studied the water balance of Utah Lake. In conjunction, Wang and Riley (1973) also estimated evaporation by the energy budget analysis, even though the necessary measurements of solar radiation, vapor pressure, and water temperatures were not available at Utah Lake. They pointed out the error in the common practice of assuming a constant coefficient of pan evaporation compared to lake evaporation. Using their evaporation estimates in the water budget analysis in the simulation of lake levels using their simulation model, they achieved a good correspondence between actual and simulated lake levels. However, it should be pointed out that they used a water budget analysis that included estimated values for both groundwater inflow and evaporation. These are both unknowns and error in one could be offset by the same magnitude of error in the other. The report of Wang and Riley (1973) includes a plot of simulated lake evaporation versus pan evaporation at Lehi. This graph results in an S-shaped curve indicating low values of the pan coefficient during months when the lake evaporation is either in the low or the high range. This seems to be inconsistent with the Lake Hefner studies (Harbeck et al. 1952 and 1954), which indicated that pan coefficients were low in the spring and early summer when lake water temperatures were low relative to the overlying air and high in the late summer and fall when the lake waters had stored a significant amount of heat.

The U.S. Bureau of Reclamation (1964), in planning for the Bonneville Unit of the Central Utah Project, used a constant evaporation pan coefficient of 0.8 applied to the evaporation pan records at Lehi in making estimates of total lake evaporation. Viers (1964) also used a constant pan coefficient of 0.8 applied to the Lehi evaporation pan record to estimate the lake evaporation.

Salt Balance Studies

All water balance factors were measured with reasonable accuracy except evaporation and groundwater inflow. Therefore, using the water balance equation alone, it was not possible to determine evaporation by this method. However, additional physical facts aid in the evaluation of evaporation: (1) evaporation is known to be relatively small during the winter months, (2) groundwater inflow from deep-seated sources is relatively constant, (3) groundwater inflow from other than deep-seated sources is related to groundwater levels around the periphery of the lake, and (4) some of the mineral ions dissolved in the lake waters are sufficiently stable that an ion-balance (salt balance) analysis can provide an additional check on water quantity estimates.

The theory of the ion-balance analysis is simple. In effect, it is a mass balance, the same as a water balance, on selected dissolved minerals in the waters. Ions are chosen that do not ordinarily precipitate out of solution (conservative ions) at the concentrations found. Ion concentrations in all incoming and outgoing waters are used in an equation similar to the water balance equation. Ion concentrations must be determined for each inflow and outflow over time. In many cases, this may be more difficult than obtaining accurate water inflow and outflow data required for both water-balance and ion-balance calculations. In the case of Utah Lake, two factors are present that make ion-balance calculations feasible: (1) the mineralized spring inflows contain a much larger proportion of sodium, potassium, sulfate, and chloride ions than do most surface and fresh groundwater inflows. Since a large uncertainty is associated with the total annual volume of these mineral inflows, this large difference in ion concentrations is extremely helpful in adjusting the magnitudes of fresh and mineralized groundwater inflows as trial water and ion balances are run; (2) a substantial amount of chemical quality information is available on the major tributary inflows, fresh groundwaters, and major mineralized inflows, as well as for the Jordan River.

The water quality simulation model (LKSIM), developed in the study of the effects of lake diking on water quality (Fuhri-

TABLE 3. Water budget analysis—Utah Lake 1 July 1970–30 June 1973 (all figures are in acre-feet of water, 1 acre-foot equals 1233.5 m^3).

Month	Precipitation on lake surface	Surface inflow	Shallow subsurface inflow	Deep Subsurface inflow	Surface outflow	Change in storage	Calculated evaporation
1970							
Jul	7,234	19,056	6,500	2,324	45,841	– 66,231	55,594
Aug	6,080	18,695	8,500	2,324	51,332	– 76,792	61,058
Sep	15,860	24,811	5,700	2,324	33,876	– 26,371	41,191
Oct	9,696	35,725	5,400	2,324	14,862	+ 14,187	24,096
Nov	19,540	49,734	6,200	2,324	8,896		
Dec	12,538	51,308	6,600	2,324	16,942		
1971							
Jan	6,102	48,794	6,800	2,324	23,096	+ 200,159[a]	34,916[a]
Feb	11,925	45,185	6,500	2,324	25,904		
Mar	2,987	48,385	7,000	2,324	31,305		
Apr	16,557	57,696	6,400	2,324	30,042	+ 27,519	25,415
May	3,815	44,661	5,800	2,324	38,586	– 22,775	40,789
Jun	2,522	42,490	4,700	2,324	40,282	– 45,024	56,778
TOTAL	114,946	486,540	76,100	27,888	360,964	+ 4,672	339,837
1971							
Jul	817	18,355	6,500	2,324	48,424	– 84,513	64,085
Aug	5,223	18,838	9,500	2,324	52,045	– 74,649	58,489
Sep	5,860	23,877	14,700	2,324	37,200	– 29,899	39,450
Oct	10,327	43,806	9,500	2,324	13,185	+ 38,921	13,852
Nov	7,783	49,299	6,200	2,324	10,322		
Dec	10,426	57,071	6,600	2,324	15,211		
1972							
Jan	277	45,592	6,800	2,324	23,790	+ 176,301	33,729[a]
33,729[a]							
Feb	133	43,748	6,500	2,324	25,791		
Mar	2,429	53,073	7,000	2,324	29,334		
Apr	9,177	44,021	6,400	2,324	26,079	+ 3,742	32,101
May	326	34,951	5,800	2,324	44,952	– 50,356	48,805
Jun	5,278	48,951	8,700	2,324	44,488	– 32,229	52,994
TOTAL	58,056	481,512	94,200	27,888	370,821	– 52,672	343,505
1972							
Jul	985	17,867	14,500	2,324	51,740	– 90,579	74,515
Aug	4,726	16,858	12,500	2,324	52,567	– 75,494	59,335
Sep	5,258	20,410	6,700	2,324	35,800	– 42,894	41,786
Oct	19,106	39,332	5,400	2,324	13,464	+ 35,247	17,451
Nov	6,442	42,653	6,200	2,324	5,286		
Dec	4,808	42,158	6,600	2,324	1,773		
1973							
Jan	7,338	48,331	6,800	2,324	6,779	+ 236,673[a]	24,917[a]
Feb	7,147	55,033	6,500	2,324	19,714		
Mar	9,499	53,766	7,000	2,324	26,753		
Apr	11,727	62,955	6,400	2,324	29,798	+ 29,999	23,609
May	8,865	136,368	5,800	2,324	39,690	+ 65,849	47,817
Jun	6,148	55,471	4,700	2,324	44,969	– 29,786	53,460
TOTAL	92,049	591,202	89,100	27,888	328,333	+ 129,015	324,890
1970–73 ANNUAL AVERAGE	88,350	519,751	86,467	27,888	353,373	–	342,077

[a]Five-month total

man et al. 1975), was used to achieve the results reported herein. Sodium and potassium cations and chloride and sulfate anions were used as the primary ions in the ion-balancing procedures. The process actually involved successive approximations to find the quantity of groundwater of particular ion concentrations, which would result in a good simulation when compared to the measured concentrations in the lake. The resulting "final" water balance is given in Table 3 and a summary of the evaporation results in Table 4. It is noteworthy that the pan coefficient (the calculated lake evaporation divided by the pan evaporation) is relatively low in the spring and increases throughout the summer. This pattern is consistent with the Lake Hefner results reported by Harbeck et al. (1952).

These simulation studies also resulted in an estimated groundwater input of 141 × $10^6 m^3/yr$ (114,355 ac-ft/yr). Others have estimated this inflow to be much smaller—perhaps 37 × 10^6 to 56 × $10^6 m^3$ (30,000 to 45,000 ac-ft/yr) (Harding 1941).

Discussion of Water Balance Results

Over the three-year period of the study, loss by evaporation was over 1250 × $10^6 m^3$ (1,026,000 ac-ft)—an average annual loss of more than 417 × $10^6 m^3$ (342,000 ac-ft). Evaporation was equal to 66 percent of the surface tributary inflow and 47 percent of the total inflow. Groundwater flow directly into the lake was calculated to be 16 percent of the total inflow and 22 percent of the surface tributary inflow.

TABLE 4. Calculated evaporation[c] from Utah Lake and evaporation from pan at Lehi, Utah, 1 July 1970–30 June 1973.

Month	Average lake area (acres)	Calculated lake evaporation[a,b] (acre-feet)	Calculated lake Evaporation (inches)	Pan Evaporation (inches)	Pan coefficient
1970					
Jul	92,018	55,594	7.33	9.39	0.78
Aug	89,940	61,058	8.21	8.82	0.93
Sep	88,467	41,191	5.58	6.20	0.90
Oct	88,292	24,096	3.25	3.47	0.94
1971					
Apr	94,772	25,415	3.20	5.16	0.62
May	94,843	40,789	5.18	6.57	0.79
Jun	93,817	56,778	7.32	9.16	0.80
Jul	91,890	64,085	8.48	10.88	0.78
Aug	89,578	58,489	7.89	9.06	0.87
Sep	88,096	39,450	5.37	6.84	0.79
Oct	88,222	13,852	1.86	no data	—
1972					
Apr	93,982	32,101	4.10	5.17	0.79
May	93,284	48,805	6.33	8.87	0.71
Jun	92,052	52,994	6.94	9.01	0.77
Jul	90,270	74,515	10.01	11.72	0.84
Aug	87,914	59,335	8.16	8.73	0.93
Sep	83,162	41,786	5.86	6.04	0.97
Oct	86,055	17,451	2.41	no data	—
1973					
Apr	93,900	23,609	3.00	4.32	0.69
May	95,360	47,817	5.95	8.23	0.72
Jun	95,910	53,460	6.72	8.97	0.75

[a]Calculated by the combined ion balance and water budget method.
[b]The evaporation pans were taken out of service during winter.
[c]Author's note—Information from very recent 1930–79 lake simulation work indicates lake evaporation to be about 10 percent higher than given in this table.
1 acre = 0.4047 hectares
1 acre-foot = 1233.5 cubic meters
1 inch = 0.02540 meter

The average evaporation pan coefficients for the summer months are as follows:

April	0.70
May	0.74
June	0.77
July	0.80
August	0.91
September	0.89

The average monthly winter evaporation for November through March was 0.0206 m (0.81 in) per month.

Lake evaporation as determined by these studies is greater than has been estimated by previous investigators. At least two significant factors are believed to contribute to the abnormally high evaporation loss from Utah Lake: (1) the shallowness of the lake, which results in the lake contents being more easily raised in temperature than would be the case with a deeper lake, and (2) the wind-caused seiches on the lake (frequent and often as much as 0.6 to 0.9 m (2 or 3 ft), which wet a large area of the shore in the southern part of Goshen Bay with every rise of the water surface. A large amount of evapotranspiration subsequently occurs from these areas.

Utah Lake Water Quality

Tributary Quality

Water that flows into Utah Lake originates from a natural drainage area of more than 7550 km^2 (2900 mi^2). Dwelling in this watershed area is a 1980 population of about 200,000 people, large numbers of wild and domestic animals, and many industrial and commercial establishments—all contributing wastes that affect Utah Lake. However, a large part of the natural and man-made pollution is assimilated in the drainage and lake system such that harmful effects to the lake are less than might be anticipated.

Table 5a gives average temperature and chemical quality data for the larger tributaries for which significant amounts of data are available (see Fig. 2 for tributary location). Data are mainly from the 1970–73 period. More recent data, particularly for 1977–1980, are not included, but cursory review of these more recent data show no substantial differences. From zero to 10 data values were available for each parameter each month; usually 2 or 3 in the winter months and 5 or 6 in the summer months. The values are simple averages; no attempt was made to flow-weight or smooth-out the data. The tabulated data are presented in the same format as the lake quality data in Table 7 to facilitate comparisons.

Tributary temperatures are generally about the same as lake temperatures, except in June when late spring runoff waters are 6 to 7 C colder and during the winter months when tributaries are several degrees warmer than the lake.

Tributary total dissolved solids (TDS) values of some 250 to 1000 mg/l may not appear significantly lower than the 800 to 950 mg/l in the main lake, but inspection of the tributary flow volumes in Table 5b shows that the major inflows—UT13 (American Fork River), UT29 (Provo River), UT44 (Hobble Creek), UT48 (Spanish Fork River)—contain only 250 to 500 mg/l TDS. Of particular note is the Provo River, which carries average TDS values of less than 300 mg/l. The Provo River carries about 30 percent of the total inflow to Utah Lake, but only about 14 percent of the TDS. Other quality parameters given follow about the same pattern relative to the lake quality as do the TDS values.

Tributary flow rate values given in Table 5b are for 1979, a year closer to average than the 1970–1973 values in Table 2.

Lake Water Quality

Public consensus would likely classify Utah Lake as badly polluted. However, scientific investigations show this is not true, if we define pollution as the quality degradation resulting solely from the activities of man.

It must be recognized what Utah Lake is: a basin-bottom lake, the natural recipient of many "pollutants" from its drainage basin; a lake adjoined by marshlakes on its east and south fringes, where most people use the lake; a lake where evaporation removes about one-half the total inflowing water, thus doubling the mean salt concentration; and a shallow lake where sediments are stirred and mixed by wave action, giving the lake a milky gray to gray brown, turbid appearance.

Most man-caused pollutants enter in tributaries on the east and south of the lake and

TABLE 5a. Average water quality values for selected Utah Lake tributaries.[a]

Temperature—C

Station	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
UT 9	3.7	6.9	10.5	11.3	14.9	–	26.0	23.2	20.6	8.8	6.5	4.0
UT13	–	–	12.6	10.7	17.5	17.0	–	19.2	16.6	–	–	–
UT18	5.8	6.7	10.8	10.3	15.6	15.0	23.2	22.6	21.9	9.9	8.2	4.2
UT29	4.0	3.6	5.9	8.0	11.5	14.3	25.0	19.6	18.6	7.8	7.4	4.7
UT34	6.4	7.8	10.5	11.9	15.1	14.5	17.8	19.7	20.2	9.6	10.7	7.0
UT38[b]	–	–	9.5	–	16.5	15.9	–	16.5	–	–	–	–
UT42	8.9	9.0	15.5	14.3	17.4	–	–	19.8	18.0	15.6	12.2	–
UT43	4.8	8.3	12.7	11.9	17.9	14.0	19.8	18.0	18.3	8.2	8.9	6.5
UT44	8.2	6.6	7.6	7.7	15.0	14.0	–	18.6	20.9	10.0	8.9	–
UT45	5.0	8.0	–	12.4	–	–	18.0	20.9	22.1	8.8	8.5	6.5
UT47	2.2	6.1	10.4	10.2	15.3	–	–	21.8	19.9	10.6	7.8	3.3
UT48	3.9	4.7	6.5	8.8	13.5	16.0	23.2	20.4	18.1	6.0	5.8	1.9

Total dissolved solids—mg/l

Station	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
UT 9	444	444	388	472	373	–	411	472	431	410	414	453
UT13	–	–	398	341	–	259	–	363	332	–	–	–
UT18	560	587	626	618	582	478	562	528	514	507	541	513
UT29	327	271	325	327	245	227	274	289	263	249	257	272
UT34	416	398	453	445	380	364	373	443	371	391	377	378
UT38[b]	–	–	378	372	405	387	386	890	394	356	890	–
UT42	798	716	718	741	670	–	–	1065	684	729	699	–
UT43	624	582	615	580	561	438	548	627	632	570	599	654
UT44	356	278	327	259	316	335	–	460	–	310	294	–
UT45	957	1150	886	958	–	–	496	552	–	692	748	839
UT47	937	1016	991	1086	778	–	–	–	–	851	873	–
UT48	552	490	535	480	496	437	722	906	486	526	494	505
UT51	841	912	883	861	1154	1405	1080	1113	857	825	841	1017

Calcium—mg/l

Station	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
UT 9	78.5	75.0	74.2	61.9	69.0	70.3	81.0	56.0	74.7	66.0	77.0	–
UT13	–	–	84.5	53.2	72.0	59.8	–	82.3	79.0	–	–	–
UT18	94.5	89.0	98.0	85.7	86.0	83.2	98.5	88.0	92.0	76.0	91.5	–
UT29	66.5	59.5	65.8	60.2	55.5	52.1	62.0	60.7	63.2	56.0	56.8	60.7
UT34	93.3	85.0	83.8	75.7	87.3	85.2	95.5	50.0	84.0	91.0	86.0	–
UT38[b]	–	–	69.0	–	71.0	74.2	85.0	100.0	77.0	88.0	85.0	–
UT42	125.0	133.0	113.0	116.0	137.0	–	–	–	122.0	132.0	132.0	17.0
UT43	107.0	111.0	102.0	97.3	109.0	98.5	99.0	84.0	98.0	82.5	107.0	–
UT44	72.7	69.7	66.2	53.8	44.0	65.9	–	78.0	75.0	73.0	88.0	68.0
UT45	–	98.0	93.0	66.8	75.0	87.7	82.0	43.0	81.0	–	82.5	–
UT47	86.0	83.0	72.8	54.8	70.0	–	–	–	–	87.0	86.0	–
UT48	84.7	81.0	72.2	60.3	62.5	65.9	73.8	80.8	68.2	–	77.4	83.5
UT51	102.0	78.0	76.5	64.9	82.0	89.0	92.5	69.0	76.0	85.0	70.6	–

Magnesium—mg/l

Station	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
UT 9	19.7	40.3	38.0	36.4	37.7	34.3	37.0	30.0	38.7	36.0	37.2	–
UT13	–	–	29.7	22.8	27.0	17.9	–	25.3	27.0	–	–	–
UT18	42.0	32.0	45.3	39.7	39.3	39.0	44.5	37.0	39.7	38.0	40.8	–
UT29	16.5	16.5	15.4	14.7	18.5	11.1	15.0	14.8	16.8	13.7	14.5	11.7
UT34	21.3	21.5	20.6	20.3	20.0	20.8	22.5	19.0	20.7	21.0	22.8	20.0
UT38[b]	–	–	22.0	–	22.0	21.4	16.0	25.6	18.5	12.0	21.0	–
UT42	43.7	43.5	41.7	37.7	41.0	–	–	–	38.0	41.0	40.0	54.0
UT43	42.0	30.0	31.4	33.8	29.3	29.0	34.5	30.0	44.0	35.0	33.0	–
UT44	14.0	17.2	16.5	10.0	11.0	18.4	–	34.0	25.0	18.0	15.8	16.0
UT45	–	68.0	60.0	42.8	43.0	41.0	33.5	54.0	48.0	–	53.0	–
UT47	54.0	50.0	49.8	33.6	39.5	–	–	–	–	51.0	50.0	–
UT48	30.7	34.0	30.4	25.7	32.0	30.4	54.7	49.2	25.8	–	28.8	31.3
UT51	67.0	66.0	56.0	59.0	83.0	83.0	86.0	81.0	60.0	65.0	64.0	–

Table 5a continued.

Temperature—C												
Station	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec

Sodium—mg/l												
Station	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
UT 9	20.0	23.3	28.4	23.6	24.7	18.3	39.5	22.0	19.7	17.0	20.2	—
UT13	—	—	30.5	15.3	29.0	36.1	7.2	12.3	13.0	—	—	—
UT18	33.0	27.5	40.9	39.3	36.5	25.8	27.0	32.0	31.0	27.0	30.2	—
UT29	11.5	11.5	12.8	10.9	12.8	8.7	12.0	10.4	13.1	—	11.0	11.3
UT34	15.0	16.0	19.0	17.3	16.0	14.2	16.0	15.0	16.7	15.0	16.7	58.0
UT38[b]	—	—	28.0	—	31.0	28.0	22.0	33.0	26.5	25.0	—	—
UT42	37.7	41.5	52.3	40.2	40.0	—	—	—	31.0	33.0	33.0	78.0
UT43	34.7	37.3	33.4	37.0	37.7	21.5	57.5	30.0	44.0	36.0	32.0	—
UT44	9.7	10.0	11.4	7.7	8.5	10.0	28.0	27.0	40.0	13.5	11.8	24.0
UT45	—	125.0	105.0	119.0	130.0	44.3	44.5	83.0	73.0	—	135.0	—
UT47	169.0	173.0	186.0	122.0	131.0	—	—	—	—	143.0	153.0	—
UT48	52.7	62.5	53.6	41.0	70.0	56.0	182.0	155.0	63.0	—	57.0	67.7
UT51	94.0	127.0	105.0	117.0	175.0	203.0	200.0	211.0	112.0	113.0	127.0	—

Bicarbonate—mg/l												
Station	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
UT 9	329	304	317	316	292	292	202	241	275	279	304	453
UT13	—	—	262	247	293	191	—	270	208	—	—	—
UT18	383	333	353	372	326	317	342	277	336	375	359	—
UT29	189	192	211	192	187	172	191	220	199	—	194	192
UT34	289	300	313	306	287	285	243	186	254	314	297	212
UT38[b]	—	—	274	282	281	272	285	294	265	277	474	—
UT42	276	256	249	282	286	—	—	—	271	278	276	—
UT43	287	285	287	291	292	226	246	208	361	310	307	—
UT44	233	232	220	198	167	200	—	314	217	260	248	158
UT45	—	558	509	437	455	430	295	303	358	—	520	—
UT47	567	456	545	410	448	—	—	—	—	525	525	—
UT48	290	310	312	309	315	324	380	462	294	—	301	296
UT51	477	483	465	464	540	561	416	482	451	520	423	—

Chloride—mg/l												
Station	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
UT 9	29.3	26.7	19.0	15.9	19.0	22.0	17.0	31.0	23.0	22.3	23.5	25.0
UT13	—	—	12.9	12.5	10.0	7.7	—	15.0	17.0	—	—	—
UT18	46.0	37.0	39.3	33.3	32.0	30.4	32.5	47.7	29.0	38.0	41.2	43.5
UT29	18.0	24.0	14.5	10.5	10.2	12.0	12.3	16.6	14.7	21.3	20.4	15.4
UT34	27.8	23.0	26.2	19.7	20.0	23.2	19.0	30.0	20.7	27.3	28.3	26.7
UT38[b]	—	—	29.0	—	29.0	33.8	—	37.0	32.0	—	42.0	—
UT42	49.3	49.0	44.7	38.2	36.0	—	—	63.0	40.0	40.0	42.0	—
UT43	52.0	48.3	35.6	43.8	44.7	24.5	48.5	70.0	53.0	57.3	60.0	80.0
UT44	19.3	17.7	9.4	5.0	10.5	15.2	—	26.0	30.5	11.0	17.5	31.0
UT45	138.0	103.0	100.0	52.2	102.0	36.0	26.0	65.3	50.0	87.5	109.0	125.0
UT47	126.0	129.0	127.0	118.0	95.0	—	—	—	—	105.0	115.0	—
UT48	71.7	70.0	50.5	37.6	51.2	42.1	121.0	100.0	46.4	87.0	62.5	66.2
UT51	98.0	103.0	85.1	94.0	167.0	157.0	194.0	215.0	108.0	123.0	121.0	156.0

Sulfate—mg/l												
Station	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
UT 9	94.0	103.0	78.2	95.6	99.5	89.5	83.5	93.0	88.0	84.0	87.8	—
UT13	—	—	104.0	72.0	—	54.2	63.0	80.5	98.3	—	—	—
UT18	107.0	98.5	128.0	112.0	110.0	108.0	122.0	110.0	90.3	100.0	102.0	—
UT29	53.0	56.5	55.4	51.0	52.7	41.6	40.5	40.7	43.3	—	52.7	54.3
UT34	53.5	60.8	54.6	57.8	58.7	57.5	68.0	58.0	55.0	61.0	60.8	59.0
UT38[b]	—	—	51.0	—	58.0	52.2	50.0	55.0	49.5	50.0	73.0	—
UT42	288.0	306.0	303.0	262.0	306.0	—	—	—	248.0	267.0	265.0	338.0
UT43	132.0	172.0	156.0	167.0	124.0	97.0	127.0	116.0	163.0	106.0	143.0	—
UT44	42.0	38.3	39.7	25.8	15.0	44.1	146.0	100.0	107.0	32.0	46.8	28.0
UT45	—	235.0	202.0	305.0	124.0	95.0	87.0	144.0	112.0	—	166.0	—
UT47	182.0	163.0	180.0	248.0	144.0	—	—	—	—	161.0	161.0	—
UT48	100.0	85.0	87.0	72.4	105.0	87.5	221.0	199.0	102.0	—	103.0	109.0
UT51	165.0	186.0	150.0	132.0	281.0	343.0	298.0	329.0	170.0	179.0	148.0	—

Table 5a continued.

					Temperature—C							
Station	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
					Nitrate—mg/l							
Station	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
UT 9	1.81	1.88	1.78	1.58	1.32	.84	1.13	.40	1.71	1.73	1.73	1.27
UT13	—	—	1.18	.557	1.42	.525	—	6.2	1.80	—	—	—
UT18	2.54	2.23	2.89	2.88	1.90	1.06	1.48	1.65	2.71	1.49	1.40	1.69
UT29	.325	.335	.400	.345	.220	.390	.313	.204	.427	.755	.188	.200
UT34	.91	.71	.93	1.22	1.66	2.16	1.92	1.51	.77	.83	.88	.80
UT38[b]	—	—	1.00	.62	1.58	1.03	11.1	4.4	4.4	—	—	—
UT42	.750	.688	.629	.611	.555	—	—	.605	.36	.68	.79	—
UT43	2.16	1.39	1.41	1.69	2.02	—	.978	1.88	.34	1.28	1.47	1.05
UT44	.900	.748	.760	.512	.442	1.28	—	.48	1.18	.84	.762	.778
UT45	1.64	1.86	2.27	1.46	2.24	1.97	1.54	1.82	2.92	3.60	1.03	1.22
UT47	3.61	2.46	2.41	2.35	2.49	—	—	—	—	1.94	4.06	4.10
UT48	.892	.467	.513	.440	.496	.58	.438	.433	.457	.35	.320	.462
UT51	1.49	1.71	1.38	1.21	.827	.770	.928	.737	.675	.887	1.11	1.20

[a]Quality data largely from the July 1970–July 1973 period, from 1 to 10 observations were available for each parameter each month.
[b]Mill Race averages are for the sampling sites below the Provo STP outfall.
--No data available.

are largely attenuated and assimilated as they pass through ponds, marshlands, and bays bordering the main lake.

Turbidity.— During much of the ice-free season, normally April through November, Utah Lake is turbid, exhibiting a milky gray appearance during calm periods to a gray brown appearance during windy periods. This turbidity contributes more than any other factor to the "polluted" image of the lake. In fact, this turbidity is a natural feature of the lake that has only been slightly aggravated by the activities of man.

The lake bed material is composed mainly of colloidal and fine silt-sized calcite crystals ($CaCO_3$), much of which is precipitated from lake waters. These particles are agitated and kept in suspension by natural wave and water current motions. During the ice-free season moderate waves 0.3 to 0.6 m (1 to 2 ft) high occur almost daily; large waves up to 1.2 m (4 ft) or more are created several times a month by moderate to high winds. These large waves thoroughly churn up the lake bed material, producing a gray brown, polluted appearance that dissipates slowly over several calmer days to the milky gray state. A green hue is added by algae during most of the summer.

Algae growth in the summer and fall increases the pH to high levels, often above 8.3, which causes the chemical conversion of abundant bicarbonate anion (HCO_3^-) to carbonate (CO_3). The carbonate then combines with the abundant calcium cation (Ca^{++}) to form a fine calcite precipitate ($CaCO_3$). These newly formed calcite crystals are normally very small and tend to remain in suspension. Over time these crystals grow larger and settle to add to the bottom sediments.

Ion balances indicate that about 300mg/l/yr of calcite precipitated during the 1930–79 period. This represents a lake total of 185 × 10^6 kg/yr (200,000 tons/yr) and an average depth of 0.4 mm/yr (0.016 in/yr) in bottom sediments. Since shallow water sediments migrate to deeper waters over time, the midlake accumulation rate would be somewhat larger. Sediment profiling investigations and mineral composition work summarized by Brimhall and Merritt in the geology paper in this publication estimate the long-term average deeper water sedimentation rate to be about 0.85 mm/yr (0.033 in/yr) and the sediments to be generally 60 to 80 percent calcite, depending on location. Therefore, about 50 percent of the total sediments and 65 percent of the calcite appear to be originating in the lake itself via mineral precipitation. A disproportionate part of the turbidity likely results from this precipitated calcite and other minor precipitates, such as the calcium phosphate compounds ($Ca_x(Po_4)_y$), since these particles are likely smaller than sediments carried into the lake by tributary inflows.

Bacterial Contamination

Coliform bacteria are frequently used as the indicator of sewage pollution and sanitary quality of waters. Some coliform bac-

TABLE 5b. Flowrates in Utah Lake tributaries during the 1979 water year—a typical, near average year (acre-feet).

	1978						1979						
Station	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Total
UT 1 & 2	122	20	0	0	0	0	0	170	66	48	13	13	452
UT 4	36	25	24	24	30	33	28	0	0	25	25	24	274
UT 5	80	80	82	82	82	91	86	114	111	51	51	49	959
UT 6	116	120	125	125	110	122	76	76	73	128	128	124	1323
UT 7	65	67	70	70	132	153	51	47	45	197	197	190	1284
UT 8	346	351	365	286	450	1533	485	377	216	204	323	124	5060
UT 9	1195	1442	1286	1534	1406	1664	780	956	1322	503	1242	966	14296
UT 10	3	0	57	118	94	45	23	71	0	33	215	291	950
UT 11	191	148	117	109	95	109	115	244	359	360	180	0	2027
UT 12	105	48	38	38	38	42	61	52	50	105	105	101	783
UT 13	25	45	46	46	82	92	66	156	326	200	54	52	1190
UT 14	86	105	112	113	109	122	132	41	126	145	173	168	1432
UT 15	191	167	169	168	218	250	133	180	223	213	170	164	2246
UT 16	229	120	103	103	62	66	110	73	236	201	123	119	1545
UT 17	375	234	172	137	142	76	100	160	341	228	331	344	2640
UT 18	1677	1303	1615	2190	1370	1286	1119	1011	883	1120	1941	1122	16637
UT 20	2142	2333	2750	2297	2074	2385	2273	2426	2085	1724	1852	2118	26459
UT 23	1	25	31	31	7	6	5	2	2	1	1	1	113
UT 25	23	63	74	74	38	38	30	33	144	105	24	23	669
UT 26	508	475	477	482	447	492	487	546	528	571	586	565	6164
UT 27	1079	1164	1278	1477	1633	1363	1179	1023	951	980	1022	1051	14200
UT 28	0	103	123	123	131	148	73	40	89	103	123	119	1175
UT 29	10340	14730	16940	17250	15430	17320	17700	6160	2360	963	2570	2530	124293
UT 31	148	160	169	169	186	210	98	92	136	108	48	46	1570
UT 32	62	109	123	123	47	46	57	119	50	49	44	42	871
UT 33	18	18	18	18	17	18	28	37	36	42	92	89	481
UT 34	402	258	317	317	317	351	249	178	653	695	591	813	5141
UT 35	154	49	31	31	7	6	1	280	42	93	264	256	1214
UT 36	18	86	103	103	81	87	67	256	115	124	156	151	1352
UT 37	62	55	57	57	65	73	71	94	91	256	280	271	1432
UT 38	499	642	999	1457	679	1115	1286	960	449	534	641	539	4800
UT 39	1342	1240	1207	1180	1160	1294	1206	1446	1496	1979	1874	1832	17256
UT 41	403	349	343	282	119	157	160	134	397	366	513	605	3828
UT 42	1210	875	1352	1356	1314	1655	1437	1768	1891	1304	1535	1699	17394
UT 43	442	723	870	650	577	663	508	327	418	110	612	584	6484
UT 44	1483	2518	3066	2731	2337	1230	9668	13091	14227	2632	0	0	52983
UT 45	201	294	349	322	348	378	270	223	105	63	20	190	2763
UT 46	135	97	133	163	246	181	141	248	243	213	318	178	2296
UT 47	945	1042	1605	2102	1527	866	418	185	46	6	263	49	9054
UT 48	2300	5040	6320	7940	6440	8770	15340	10360	792	181	334	561	54378
UT 48a	31	42	46	46	79	92	55	36	100	94	62	60	743
UT 49	15	15	15	15	78	92	41	15	15	60	63	61	485
UT 50	106	102	143	110	579	238	115	323	400	284	150	313	2863
UT 51	1530	2098	2099	2519	2893	4582	2557	1292	390	370	1036	639	22005
UT 52	54	187	188	336	2122	1518	612	303	147	0	0	0	5467
TOTAL	30,495	39,167	45,607	48,904	45,398	51,058	59,497	45,725	32,775	17,826	20,345	19,234	446,031

[a]Tributaries UT 3, UT 19, UT 21, UT 22, and UT 40 had no flow; UT 40 is being diverted into UT 41.
One acre-foot equals 1233.5 m^3

teria are always found in the lake. The highest counts usually occur near municipal sewage plant discharges and main tributaries. Headman, Ferguson, and Corollo (1949), in a study conducted prior to the construction of any sewage treatment facilities in the area—when considerable raw sewage was discharged—found considerable bacterial pollution near raw sewage discharges along the east shore, as would be expected. However, they also noted the low bacterial levels farther out in the lake. Fuhriman et al. (1975) reported considerably lower bacterial counts in these near-shore areas (presumably a reduction resulting from construction of sewage treatment facilities) with decreases farther out in the lake. Recent samples along the east shore only occasionally exceed the

generally accepted swimming water limit of 1000 total coliform per 100 ml. Higher levels normally occur at the mouths of tributaries, which are contaminated in various ways. Pollution from recreation itself may cause high coliform counts in heavy-use areas, such as boat launches and popular fishing areas. Coliform counts away from the shoreline and embayment areas seldom exceeded 100 MPN/100 ml and are usually much lower.

Biochemical Oxygen Demand

Biochemical oxygen demand (BOD) is a measure of the readily degradable organic matter; it is defined as the oxygen required for microbes to "stabilize" the organic matter present. Utah ambient water quality standards for recreation and aesthetics (class 2 waters) call for a BOD value of less than 5 mg/l. This standard is intended to protect against gross pollution and to avoid low oxygen levels from degradation of organic material. Culinary supply is an unlikely beneficial use of Utah Lake waters because of high TDS and turbidity.

Most BOD data for Utah lake have been taken since 1970. The main lake experiences average summer BOD values of 2 to 4 mg/l, Goshen Bay somewhat higher values at 3 to 6 mg/l, and Provo Bay considerably higher values at 5 to 20 mg/l. Table 6 gives data collected during 1975 by Merritt et al. (Mountainland Association of Governments, 1976). As can be seen in Table 6, some violations of the class 2 BOD standard occur in the lake. In the main lake, these BOD violations result mainly from dead in situ biomass, mainly algae. BOD values are highest with algae dieoff in the fall when high oxygenation from wave-induced mixing largely precludes serious oxygen depletion, as is the case during all the ice-free season. Only a few oxygen and BOD tests have been run on samples from under the ice, and some low oxygen problems exist where the water is less than 1 m deep. They are not pervasive since summer algae have largely died and decomposed before ice cover and fall storms fully oxygenate the lake.

Goshen Bay is much shallower, and wave action and turbidity are generally less than in the main lake. Large expanses of emergent aquatic plants and attached and floating algae are found in the bay, particularly in the shallows. As this organic debris decomposes in the winter, localized low oxygen or anoxic pockets develop under the winter ice but usually are not widespread. BOD loadings from Goshen Bay tributaries are negligible; hence, this is an uncontrollable problem unless in-lake measures are taken to control the growth of the aquatic plants. It is likely that Goshen Bay has been essentially this way for thousands of years.

Provo Bay and several similar, but smaller, bays along the east side of the lake periodically carry high BOD values. These values would generally be higher than those of the main lake, even in the absence of man's activities, as a result of the periodically high BOD loads carried by inflowing tributaries and the high biological productivity in these marsh and pond areas. Thus, even in precolonization times, periodic anoxic conditions occurred in these waters. Until the construction of secondary treatment plants in the 1950s most of the sewage generated in Utah Valley drained into Utah Lake untreated.

TABLE 6. Typical BOD values in Utah Lake (5 day, 20 C values in mg/l).

				Averages[a]	
Station[b]	Number of samples	Minimum	Maximum	With September sample	Without September sample
UL11	4	1.6	6.2	2.9	1.8
UL13	4	<1	8.3	3.6	2.0
UL15	4	1.2	11.5	4.5	2.2
GB 2	5	2.0	20.0	6.6	3.3
PB 2	4	7.1	22.1	12.4	9.2
PB11	4	3.6	12.4	6.4	4.4

[a]Samples taken in July, August, September, and November 1975. Those taken 13 September 1975 were generally from two to four times higher in BOD than for other months, probably due to a heavy algae dieoff.
[b]See Figure 2 for station location.

TABLE 7. Average water quality values for selected locations in Utah Lake.[a]

Temperature–C

Station	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
UL11	11.7	9.9	16.9	22.5	23.8	–	18.7	–	4.9	–
UL13	11.0	10.7	19.8	24.5	24.0	18.9	19.0	9.4	5.0	–
UL15	–	10.8	12.1	24.5	24.3	–	18.7	–	4.6	–
GB 2	–	11.5	13.8	22.2	24.8	21.2	18.4	–	4.5	–
PB11	3.5	12.0	–	25.4	22.1	23.3	17.6	9.4	4.0	2.0
PB 2	4.0	10.2	12.2	14.6	27.0	23.8	17.4	14.5	6.1	–

Total dissolved solids–mg/l

Station	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
UL11	794	955	894	923	913	913	922	918	893	856
UL13	880	887	854	924	934	915	889	943	891	938
UL15	1073	840	964	969	925	935	925	925	937	941
GB 2[b]	–	965	–	–	948	–	1145	–	890	–
GB 2[c]	–	–	–	2260	2009	2269	–	–	–	–
PB11	751	762	808	–	906	870	898	890	872	835
PB 2	586	532	–	584	529	525	563	575	627	–

Calcium–mg/l

Station	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
UL11	49	53	58	59	54	46	40	49	51	48
UL13	50	44	58	58	51	46	41	43	42	50
UL15	50	50	62	59	51	48	41	40	44	49
GB 2	–	56	–	–	58	45	42	–	49	–
PB11	–	54	68	–	55	45	40	49	49	–
PB 2	–	63	90	–	56	96	39	96	83	–

Magnesium–mg/l

Station	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
UL11	52	51	54	53	54	55	59	58	54	51
UL13	52	49	54	53	54	57	56	58	55	56
UL15	59	48	58	56	57	58	58	58	56	57
GB 2	–	54	–	–	71	64	55	–	57	–
PB11	–	45	54	–	48	58	55	57	58	60
PB 2	–	30	32	–	36	30	43	26	40	–

This raw sewage with a BOD of about 150 mg/l resulted in serious oxygen depletion. Secondary treatment plants discharge a BOD of about 30 mg/l and increase in sewered population increased the total BOD load entering Provo Bay to a point where ambient BOD concentrations are periodically as high as 20 mg/l, or more. Most significantly impacted have been the eastern reaches of Provo Bay, which receives urban runoff and treated sewage discharges from Provo and Springville (1980 population of about 85,000 people), and Powell Slough, which receives the treated sewage discharge from Orem (1980 population of about 50,000 people). These discharges compound the natural oxygen depletion problem mentioned above and extend the total area affected; however, it is debatable whether any significant increase in overall environmental degradation and damage results from the marginal oxygen depletion caused by these treated wastewater discharges.

The State of Utah is striving to achieve a reduction in BOD to 15 mg/l in all wastewater effluents by July 1983. At the present time only Provo is meeting this requirement—through its enlarged and upgraded sewage treatment facility completed in 1978. Although achievement of this requirement will reduce the ambient BOD somewhat, particularly in the receiving streams, significant long-term improvement in the aquatic habitat of these bays is doubtful. BOD from decaying vegetation, including algae, is likely dominant during the periods when the most serious oxygen depletion occurs, namely in the late summer and under the winter ice.

Total dissolved salts.— Total dissolved solids (TDS), which range from 700 to 1000

Table 7 continued.

Sodium—mg/l

Station	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
UL11	115	144	142	141	143	148	160	150	147	140
UL13	160	143	152	144	153	153	159	170	160	168
UL15	190	133	156	168	153	157	170	164	160	162
GB 2[b]	—	170	—	—	180	—	247	—	160	—
PB11	—	130	145	—	140	175	172	160	146	—
PB 2	—	60	69	—	81	33	124	31	54	—

Bicarbonate—mg/l

Station	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
UL11	225	246	248	249	228	213	194	212	224	219
UL13	239	250	269	248	226	209	193	195	219	220
UL15	242	248	266	254	230	215	247	204	231	229
GB 2	—	267	—	—	207	196	168	—	256	—
PB11	—	224	214	—	201	186	177	207	222	226
PB 2	—	226	245	—	140	251	110	252	273	—

Chloride—mg/l

Station	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
UL11	165	176	178	197	197	206	209	206	195	185
UL13	—	190	194	196	201	213	213	228	212	218
UL15	260	179	198	214	245	218	226	223	225	220
GB 2[b]	—	222	—	—	226	260	272	—	232	—
PB11	—	157	173	—	176	—	254	273	177	185
PB 2	—	73	49	—	88	88	76	32	62	—

Sulfate—mg/l

Station	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
UL11	184	202	206	222	226	240	248	245	220	210
UL13	189	198	210	220	229	243	242	254	237	231
UL15	246	208	213	225	238	258	249	251	239	227
GB 2[b]	—	213	—	—	230	296	233	—	229	—
PB11	—	157	205	—	202	248	250	242	216	219
PB 2	—	124	121	—	141	120	—	128	146	—

[a]Values are averages of all available data from 1968 through May 1976, except as noted. This was generally a wet period with lake levels somewhat higher than the long-term average. During lower water level periods, there is less mixing between Goshen and Provo Bays and the main lake; hence, Goshen Bay would have higher mineral levels and Provo Bay lower levels.

[b]Based on 1975 and 1976 data.

[c]Based on 1970 data. This shallow area in the south part of Goshen Bay is affected strongly by lake level.

mg/l in Utah Lake during typical inflow years and lake levels, are relatively high as compared to drinking water standards, which recommend a 500 mg/l TDS upper limit. Other fresh waters in the area, including the lake's major tributaries, contain about 250 to 500 mg/l. Irrigation water quality requirements vary, depending on crop type, drainage, soil, etc., but it is an incipient problem at about 1000 mg/l in this case because lands irrigated with these waters in Salt Lake Valley are already alkaline and poorly drained.

TDS in Utah Lake sometimes have rather large spatial and temporal variations. In the past, these variations have not always been properly interpreted. Cameron (1905) incorrectly interpreted an increase in salt content of water samples from the lake in 1904 compared with an 1883 sample as an indication that irrigation in the drainage basin was causing permanent decline in water quality. The error of this interpretation was pointed out by Decker and Maw (1933) and by Viers (1964)—who indicated the fallacy of using a single sample at an unknown location on the lake (as reported by Clarke in 1884) as being representative of the entire lake. Viers (1964) presented data to show that the salt concentration in the lake was not permanently increasing with time. Concentrations do increase in summer months when evaporation is high, and they are always higher in Goshen Bay and lower in Provo Bay than in other parts of the lake. Table 7 shows differences in several parameters, including total dissolved solids, in the lake at

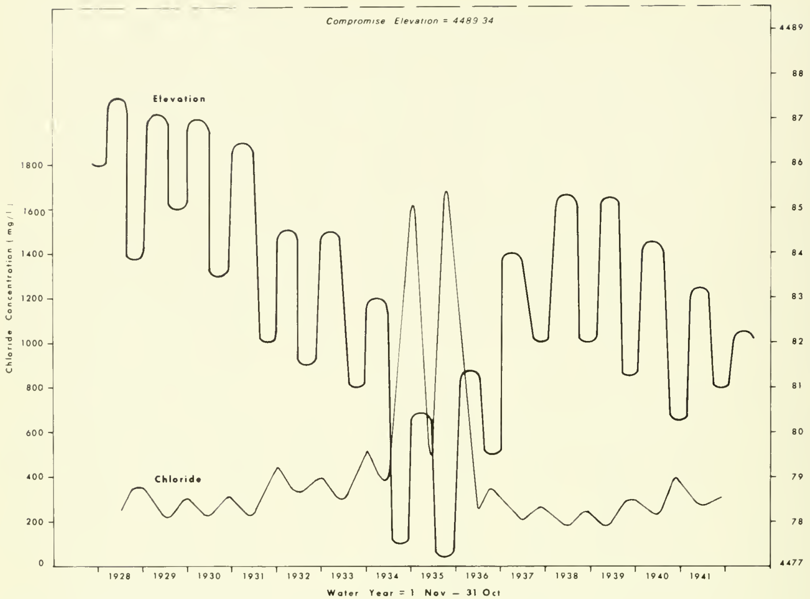

Fig. 3. Utah Lake water elevation and chloride ion concentration, 1928–1941.

TABLE 8. Water and salts percentages to Utah Lake by source—July 1970 to July 1973.

Inflow category	Annual average volume acre-feet	Annual average volume Percent	Percent of total loading to Utah Lake TDS	Na	Ca	Mg	K	Cl	HCO_3	SO_4
Surface	519,751	82.0	61.3	38.8	77.2	76.8	47.4	37.1	73.8	63.7
Shallow subsurface	86,467	13.6	17.4	27.6	15.3	12.9	22.1	18.1	21.2	20.4
Deep subsurface	27,888	4.4	21.3	33.6	7.5	10.3	30.5	44.8	5.0	15.9
TOTAL	634,106[a]	100.0								

[a]Precipitation is not included since it carries essentially no TDS—see Table 3.

different locations by months. Table 7 values are based on data taken during the 1968 through 1975 period, a relatively wet period with lower TDS concentrations, due to the increased inflow of low TDS surface waters, and high lake levels. During high-level periods, there is more mixing and circulation in the lake proper, as well as with Provo and Goshen Bays, and spatial variations are less pronounced than during lower lake levels.

During a prolonged, several-year dry cycle, lake inflow may drop markedly but evaporation continue, thus causing a large increase in TDS. Figure 3 shows this response for the driest period on record, which occurred during the 1930s. Data were taken from simulations done by the U.S. Bureau of Reclamation (1961). Chloride ion concentration increased from normal levels of about 200 mg/l to a peak of 1700 mg/l during the summers of 1934 and 1935. Since a proportionate increase in other ions likely occurred, TDS values in excess of 4000 mg/l were probably present at that time.

Table 8 gives the relative quantities of salts (TDS) carried by major categories of inflow to Utah Lake. These values were obtained from the LKSIM model discussed earlier. The

values for deep subsurface inflow are the most open to future revision, since limited data are available for the mineralized springs. Many of these springs and seeps occur in the lake bed itself and cannot be located and sampled in most cases. Mineralized springs for which some data were available are Saratoga Hot Springs, Bird Island Springs, Lincoln Point Springs, Goshen Bay North Springs, and Goshen Bay South Springs. Since the mineralized springs are the major sources of sodium, potassium, chloride, and sulfate ions—which were needed to obtain a good salt balance in the lake—the five springs given above were selectively increased in flow volume until the "best" salt and water balances were achieved. In other words, it was assumed that the quality of other unidentified mineral springs in the lake could be represented by the quality of those identified. In actual fact, co-mingling of mineral and fresh waters likely occurs prior to emergence into the lake.

Values given in Table 8 indicate the large impact that mineralized inflows have on TDS and ion concentrations in the lake—a much larger impact than previously recognized. For example, mineralized springs provide only 4.4 percent of the water but 21.3 percent of the TDS, 33.6 percent of the sodium, and 44.8 percent of the chloride.

Trophic Condition

Utah Lake is highly eutrophic, meaning that it has a large nutrient loading and experiences very high algal productivity. Procella and Merritt (1976) reported that algal bioassays on Utah Lake waters, using *Selenastrum capricornutum* as the test alga, indicate phosphorus to be the limiting nutrient, although standard chemical tests indicate a relative abundance of phosphorus as well as nitrogen in the water samples. These algal bioassays were run on waters collected at several sites in September and November 1975 and May 1976. They postulated that high hardness and high pH of the lake waters result in precipitation and/or chemical binding of phosphorus, thus rendering it less available to the algae. Nearly all bioassays also exhibited a delayed response to phosphorus and nitrogen additions, indicating that trace metals were not readily available and their release rate from precipitates was a controlling factor in the growth response. This is an expected phenomenon in these high alkalinity and high pH waters, where precipitation of most trace metals with the relatively abundant carbonate ($CO_3^=$) and hydroxide (OH^-) ions would be expected. Overall, algae productivity is likely limited in the lake itself by the high turbidity, although no in situ algal-growth experiments have been run to precisely quantify this factor.

Merritt, Rushforth, and Anderson (1976) reported nutrient loadings to Utah Lake as shown in Table 9. About 95 percent of the total phosphorus load comes from surface tributaries. About 68 percent of this load comes from treated municipal sewage effluents that flow into these tributaries. Somewhat less than 68 percent actually reaches the lake since some phosphorus precipitation, sedimentation, and biological uptake occurs prior to reaching the lake.

The mean annual total phosphorus concentration from all waters flowing into the lake is about 0.20 mg/l, which is an extremely high loading for a "fresh-water" lake with a water retention time of about one and one-half years if based on total inflow and about three years if based on outflow. Evaluations by Merritt et al. (1976) show removal of all phosphorus from sewage effluents would still leave the lake with a "eutrophic" ranking according to results obtained from a commonly used eutrophication model (Larsen and Mercier 1975).

These findings cast considerable doubt on the feasibility of controlling algae production in Utah Lake via nutrient control in tributary waters. It appears that sufficient nutrients are present "naturally," i.e., from uncontrollable sources, to provide an abundance of nutrients to the lake as a whole. It also appears that, due to high alkalinity, pH, and hardness, most of the phosphorus and trace metals are chemically bound in precipitates, and nutrient availability is controlled more by solubility and solubization rates than by the total nutrient loadings to the lake. In addition, as mentioned above, the turbidity is probably the real factor limiting total algal biomass in the lake, not nutrients. Much larger algal biomasses are generally observed in lower turbidity, sheltered areas, thereby qualitatively supporting this proposition.

TABLE 9. Nutrient budget for Utah Lake[a].

Source	Inflow acre-feet/yr	%	Inorganic nitrogen kg/yr	%	Total phosphorus kg/yr	%	Orthophosphorus kg/yr	%
Surface inflow	520,000	72.1	1,745,400	95.7	184,000	95.5	135,000	97.4
Sewage effluents	(26,900	3.7	275,100	15.1	126,000	65.4	105,000	75.7)
Shallow groundwater	86,500	12.0	40,570	2.2	2,780	1.4	2,130	1.5
Deep groundwater	27,900	3.9	5,500	0.3	520	0.3	450	0.3
Precipitation	86,500	12.0	32,000	1.8	5,340	2.8	1,070	0.8
Total inflow	720,900		1,823,470		192,640		138,650	
Surface outflow	353,000	49.0	289,800	15.9	159,000	82.5	54,800	39.5

[a]Flows are averages for July 1970 to July 1973, a period from 10 to 15 percent above the long-term average. Nutrient quantities were based primarily on 1974 and 1975 data. Phosphorus data prior to 1974 seem to be inaccurate.

[b]Sewage effluents discharge into surface tributary waters and their impact is included in the surface inflow values. These effluents are from the following: Lehi, American Fork, Pleasant Grove, Orem, Provo, Springville, Spanish Fork, Salem, and Payson. These plants serve a combined 1975 population of 144,000. The sewered population is projected to increase to 284,900 by 1995 (Mountainland Association of Governments 1976).

1 acre-foot/year = 1233.5 m^3/yr

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AQUATIC AND SEMIAQUATIC VEGETATION OF UTAH LAKE AND ITS BAYS

Jack D. Brotherson[1]

Abstract.— Seven aquatic and semiaquatic communities surrounding Utah Lake and its bays are described. Similarities and differences in the community types are discussed. Prevalent species in each type are given. The flora contained 483 species, 150 of which were prevalent enough to be included in the quantitative data analysis. *Distichlis stricta* was the most important and widespread species. Total cover varied in the communities from 10 to 77 percent. Asexual reproduction was shown to increase in importance as moisture in the soil increased. Introduced exotic species were shown to invade most successfully those habitats that show the greatest variability in moisture and/or those that have the greatest internal variation.

Initial comments on the vegetation surrounding Utah Lake were recorded as early as 23 September 1776. Fathers Atanasio Dominguez and Silvestre Velez de Escalante and their party camped on that date adjacent to the southeast shore of the Lake, and it was during their stay that they penned the first known records concerning plant communities in the area. They recorded wide meadows, abundant pasture, and marsh communities on the shores of Utah Lake and noted the prevalence of poplars, willows, flax, and hemp along the streams and east side of the lake (Chevez and Warner 1976). Other early visits were made to the area by trappers, mountain men, and explorers. However, their written records yield little information on the vegetation of Utah Lake that is not extractable from the Dominguez-Velez de Escalante journals. We learn from their writings of occasional bogs, communities containing reeds and abundant marsh grasses, infrequent patches of wild sage, and swamps filled with *Lemna* and *Chara* (Wakefield 1933).

More detailed studies of the plant communities found in and around Utah Lake have been made only in the past 50 years. Cottom (1926) made the first quantitative studies of the vegetation of the lake. He listed 11 formations and 20 associations that he described as making up the vegetation around Utah Lake and adjacent Utah Valley. Wakefield (1937) reported on vegetational changes over a six-year period on the lakeshore south of the present Provo boat harbor. Beck (1942) and Murphy (1951), in conjunction with studies of passerine birds found in the vicinity of the lake, studied and classified the plant communities frequented by the birds on Bird Island and the area from the mouth of Provo River to the south end of the Provo Municipal Airport. Barnett (1964) studied waterfowl habitat at Powell's Slough on the east shores of the lake. He placed the vegetation found there into four major communities based upon habitat type and plant species present. Christensen (1965) studied two *Tamarix ramosissima-Salix amygdaloides* stands near the mouth of the Spanish Fork River and predicted that *ramosissima* (which he understood to be *T. pentrandra*) as a type would eventually replace *Salix amygdaloides* as these trees die. Foster (1968) in a statewide study of the major plant communities of Utah recognized four community types around Utah Lake. His plant community types are broad in definition and based on observation rather than analytical data. Coombs (1970) examined the vascular aquatic and semiaquatic vegetation around the lake and delimited 29 plant communities in 7 major types. Local taxonomic and ecological studies (e.g., Weight 1928, Leichty 1952, Lawler 1960, Bessey 1960, Arnold 1960, White 1963, Skougard 1976) have been of great value by identifying many of the plant species growing in and around the lake.

Even though Utah Lake and its environs is in many localities well studied from the natural history and ecological points of view,

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little has been reported in the literature with regard to (1) man's impact on the plant communities since settlement, (2) the influence and changes wrought by introduced exotic plants, (3) species composition for the major community types, (4) environmental factors influencing the distribution of major community types, (5) community diversity, and (6) information with regard to successional changes and life form patterns along environmental gradients.

Methods

Forty stands of data were selected from the literature (Coombs 1970, Barnett 1964, Christensen 1965) and combined with 10 stands studied by the author in the summer of 1974. Percent sum-frequency values for each species (Phillips 1959), total cover information (Brown 1968), and moisture index values (Coombs 1970) were then assigned to all 50 stands. Percent sum-frequency figures were used to give the species data from the different sources equivalent standing. Where information was questionable and/or lacking (especially with respect to moisture information), supplementary field observations were made in the summer of 1976. Of the stand data taken from the literature only those having relatively complete information were used in this analysis.

Species lists (150 total) were assembled for each stand. Importance values (Warner and Harper 1972) were then computed for each species in relationship to the total vegetative complex and the major communities found in the area. From this information, prevalent species tables were compiled (Tables 4–9). The number of prevalent species included on any one list was equal to the mean number of species reported for the stands of a given community. The prevalents are listed in decreasing order of importance and are the most frequent species in the community; uncommon or rare species are ignored.

Diversity indices (McArthur 1972) were computed from the percent sum-frequency data using the formula:

$$DI = 1/\Sigma\ pi^2$$

where Di is the diversity index and pi is the relative proportion each species contributes to the overall composition of a community.

Ultimately, each stand and/or community was compared to all other stands and/or communities. This process resulted in the production of interstand or intercommunity similarity index values (Ruzicka 1958). A matrix of similarity index values was constructed. The similarity values were clustered by the pair-group clustering procedures described by Sneath and Sokal (1973).

Moisture index data were assigned to each stand using a modification of the methods employed by Coombs (1970). Moisture classes were set up as reported in Table 2.

Floristics and nomenclature follow Cronquist et al. (1977) for the monocotyledons and Holmgren and Reveal (1966) for the dicotyledons.

Results

General Vegetation Descriptions

The aquatic and semiaquatic communities surrounding Utah Lake form a band of vegetation along the lake shore varying in width from 20 m or less on the western shore to 400 m on the eastern shore. In addition, two large bays, Provo Bay and Goshen Bay, extend away from the lake in eastern and southern directions, respectively, and contain a majority of the land area occupied by the aquatic and semiaquatic communities.

During this investigaton 483 plant species were found to be part of the Utah Lake vegetation. Of these, only 150 were of sufficient importance to include in the quantitative data analyses. Only 13 species were included in a prevalence list for the entire area and, as can be seen from Table 1, the list is highly

TABLE 1. The prevalent species found in the vegetation of Utah Lake with their importance value.

Scientific name	Importance value
Distichlis spicata	3364
Scirpus americanus	2587
Eleocharis palustris	2315
Juncus balticus	1832
Carex nebraskensis	1318
Tamarix ramosissima	1094
Scirpus acutus	1039
Hordeum jubatum	1033
Typha latifolia	1030
Lemna minor	945
Sporobolus airoides	662
Salicornia rubra	606
Ambrosia artemisifolia	586

dominated by grasses and sedges, with *Distichlis stricta* being the most important and widespread species.

Seven major vegetative types exist around the Lake (Tables 2 and 3), each occupying unique habitats and each showing varying degrees of internal structure with respect to subcommunity dominants. This subcommunity variation is related in some degree to the prominance of asexual reproduction (by rhizomes) in the dominant species. When dominant species reproduce vegetatitively, large areas may be occupied almost exclusively by a single species or clone even though the abiotic environment is homogenous.

Average values for selected environmental variables are given for the seven major vegetative types in Table 2. It will be seen that the number of stands considered for each community is not equal, varying from 5 to 16. The communities vary with respect to moisture from continuous inundation to seasonal inundation, and finally to those that never experience standing water or high water tables. Communities on the dry end of the

TABLE 2. Selected environmental characteristics of major plant communities surrounding Utah Lake.

Community	ID no.	No. stands considered	Moisture[1] index	Variation[2] in moisture	Exposed surface water	Percent soil exposed	Percent litter cover
Pondweed communities	1	5	1.0	0.0	91.20	0.00	0.00
Bulrush-cattail marshes	2	7	1.0	0.0	26.47	2.51	20.64
Spikerush-bulrush meadows	3	7	1.75	0.26	7.57	5.07	13.02
Grassrush-sedge meadows	4	16	2.13	0.34	1.16	15.52	6.67
Lowland woody communities	5	11	1.86	0.43	23.90	12.53	12.18
Saline terrestrial communities	6	5	3.20	0.34	0.00	72.20	1.90
Annual herbaceous communities	7	4	2.50	0.51	0.00	50.55	20.70

[1]Moisture index is as follows: (1) substratum inundated continuously; (2) substratum seasonally saturated; (3) substratum well drained; (4) substratum dry.
[2]Moisture variability is expressed as a coefficient based on variation on means and standard deviations of moisture index values for individual stands.

TABLE 3. Biotic characteristics of major plant communities surrounding Utah Lake.

	Community Type						
Community characteristic	Pondweed	Bulrush-cattail	Spikerush-bulrush	Grass-rush-sedge	Lowland woody	Saline terrestrial	Annual herbaceous
ID no.	1	2	3	4	5	6	7
$\bar{X}$ no. of species/stand	1	12	17	18	9	5	19
$\bar{X}$ percent living cover	9.8	40.0	74.4	76.6	53.5	26.1	28.8
$\bar{X}$ diversity	0.1	4.1	6.0	6.8	3.31	2.9	10.4
Dominant life form	Aquatic forb	Cattail sedge	Sedge forb	Sedge grass	Shrub	Shrub annual	Annual
Trees	*0.0	0.3	0.2	0.2	13.1	0.0	0.3
Shrubs	0.0	0.3	0.1	0.4	43.4	49.5	3.3
Grasses	0.0	3.3	14.6	28.5	16.1	4.7	8.5
Sedges	0.0	31.3	47.0	40.1	5.5	0.0	4.8
Forbs	100.0	26.8	25.6	21.5	9.1	0.7	22.4
Annuals	0.0	7.8	12.4	9.4	10.5	45.2	60.7
Cattails	0.0	26.5	0.2	0.1	0.3	0.3	0.0
Nonvascular	0.0	3.9	0.0	0.0	0.0	0.0	0.0
Introduced exotics	0.0	1.4	10.7	9.7	38.4	5.4	33.9

*Numbers represent percent relative frequency

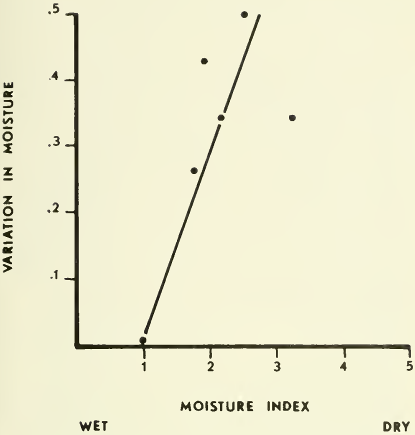

Fig. 1. Variation in moisture in the communities of Utah Lake in relationship to moisture index.

scale exhibit the greatest fluctuations in moisture (Fig. 1). The amount of exposed soil varies among the communities from less than 15 percent to slightly less than 50 percent in the playa and beach communities.

Compositional data for the seven community types is given in Table 3. Each community is dominated by a different set of life-form types, with annuals being especially prevalent in the playa and beach areas. In only two cases do particular life form types become sufficiently abundant to contribute over 50 percent of the plant cover. Generally, the vegetation of the communities considered includes species from several life form classes.

Diversity measurements varied from low values for pond weed communities to high values for the annual herbaceous communities. However, even though the diversity indices varied considerably, no significant correlations could be established between diversity and other parameters.

Similarities between the seven community types are evident since some species show dominance in more than one type (Tables 4–9). To better understand these interrelationships and to assess the degree of uniqueness of the different community types (Tables 2 and 3), a graphical summary of intercommunity similarity is presented (Fig. 2).

TABLE 4. The prevalent species found in the bulrush-cattail marsh communities of Utah Lake with their importance values.

Scientific name	Importance values
Typha latifolia	6814
Lemna minor	6243
Scirpus acutus	5471
Berula erecta	3457
Eleocharis palustris	1771
Spirodela polyrhiza	1257
Riccia fluitans	957
Polypogon monspeliensis	657
Epilobium adenocaulon	614
Lycopus lucidus	314
Nasturtium officinale	300
Scirpus americanus	286

TABLE 5. The prevalent species found in the semiaquatic herbaceous meadow communities of Utah Lake with their importance values.

Scientific name	Importance values
Eleocharis palustris	9229
Carex nebraskensis	4914
Distichlis spicata	2929
Scirpus americanus	2271
Trifolium hybridum	2029
Lycopus lucidus	1629
Scirpus validus	1429
Panicum capillare	1371
Polygonum coccineum	1357
Polygonum amphibium	1100
Iva axillaris	943
Plantago major	943
Ambrosia artemisifolia	800
Agrostis alba	771
Bidens cernua	714
Polypogon monspeliensis	614
Xanthium strumarium	557

In the cluster diagram, communities that are most similar appear close together. The horizontal line connecting any two communities shows the degree of similarity between those entities. Figure 2 demonstrates that each community recognized is highly unlike all other communities considered. The most similar entities are the Spikerush-bulrush meadows and the Grass-rush-sedge meadows, which are only 25 percent similar. Other similarity patterns exist, but the similarity percents are so low that the community types involved can be considered essentially independent of each other.

Community Type Descriptions

Pond Weed Communities

The pond weed communities are continuously inundated by water. They are essen-

TABLE 6. The prevalent species found in the grass-rush-sedge meadow communities of Utah Lake with their importance values.

Scientific name	Importance values
Distichlis spicata	7206
Scirpus americanus	6650
Juncus balticus	5033
Eleocharis palustris	2125
Hordeum jubatum	2113
Carex nebraskensis	1756
Sporobolus aeroides	1588
Glaux maritima	1488
Ambrosia artimisifolia	1156
Potentilla anserina	994
Lycopus lucidus	838
Trifolium hybridum	819
Polypogon monspeliensis	613
Ranunculus cymbalaria	606
Plantago major	606
Iva axillaris	438
Aster brachyactis	381
Suaeda occidentalis	363

TABLE 7. The prevalent species found in the lowland woody communities of Utah Lake with their importance values.

Scientific name	Importance values
Tamarix ramosissima	4573
Salix amygdaloides	2345
Salix exigua	2291
Distichlis spicata	1964
Elaeagnus angustifolia	1809
Hordeum jubatum	1036
Populus fremontii	982
Myriophyllum verticillatum	873
Xanthum strumarium	791

TABLE 8. The prevalent species found in the saline terrestrial communities of Utah Lake with their importance values.

Scientific names	Importance values
Salicornia rubra	6060
Allenrolfia occidentalis	5460
Kochia americana	3840
Sarcobatus vermiculatus	1340
Suaeda nigra	1290

tially monospecific (*Potamogeton latifolius*) types that occupy the open water areas of the lake. No other communities are found at equivalent depths. As a consequence, this community is analytically distinct from all other communities. Stand dimensions in the lake range from about 8 to 400 square feet (the largest being some 40 feet long by 12 feet wide). Stands occur in water as deep as 8 feet, but depth is variable. Coombs (1970) recorded that in June 1967 David A. White counted 137 stands in the open water of Utah Lake. Stands are found along the shoreline less frequently.

TABLE 9. The prevalent species found in the annual herbaceous communities of Utah Lake with their importance values.

Scientific names	Importance values
Polygonum lapathifolium	5700
Chenopodium glaucum	4100
Xanthium strumarium	3700
Panicum capillare	3700
Sesuvium verrucosum	2150
Malva neglecta	1950
Ambrosia artemisifolia	1900
Scirpus maritimus	1650
Aster frondosus	1550
Verbena bracteata	1450
Distichlis spicata	1450
Polypogon monspeliensis	1100
Sitanion hystrix	950
Rumex crispus	850
Trifolium spp.	850
Sporobolus airoides	800
Tamarix ramosissima	700
Grindelia squarrosa	450
Salix exigua	450
Taraxacum officinale	450
Medicago sativa	450

Bulrush-Cattail marshes

The Bulrush-cattail marshes also tolerate continuous inundation. The water depth fluctuates but generally does not exceed 2 feet and is often at ground level. The soil is characterized by considerable organic matter. Stands supported 12 species on the average but were dominated by *Typha latifolia* and *Scirpus acutus* (Table 4). In general appearance, this type appears somewhat like a giant jigsaw puzzle, with the major dominants growing in dense monospecific stands and overlapping with each other in only narrow zones. Along their edges and in areas where the cover is more open, one finds more mixing of the dominant species and increased species diversity. It is in these more open areas that many of the subdominant species (Table 4) are found.

The community occurs in three major habitat types (i.e., in the lake, adjacent to spring-fed bogs, and along irrigation canals). The type is extensive around the entire shoreline

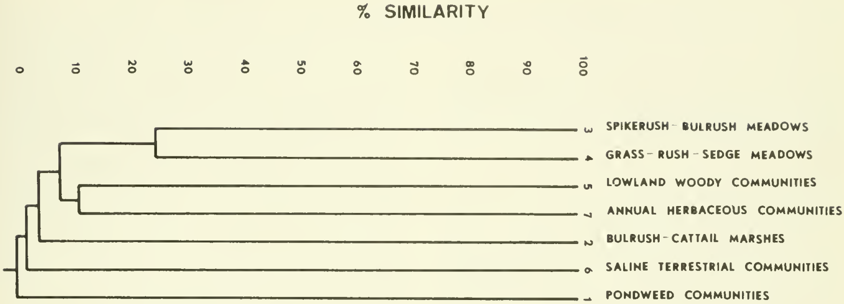

Fig. 2. Community similarity analysis reported as a cluster diagram based on plant composition of the Utah Lake communities.

of the lake, but reaches maximum development in Provo Bay and Powell's Slough.

Whether *Scirpus acutus* or *Typha latifolia* dominates any particular marsh seems to be largely a matter of priority, according to Cottam (1926). This observation tends to support the concept that the subcommunities defined by Coombs (1970) can be partially accounted for by patterns in asexual reproduction of the dominant species.

Spikerush-Bulrush Meadows

The spikerush-bulrush meadow communities are generally situated in areas that are inundated in the early seasons of the year but dry by September. The soil of the community varies but generally consists of peaty sandy loams (Coombs 1970). Organic matter content of the soil is high and, in places, the community occurs on peat beds that are 30 inches deep. The type averaged 17 species per stand; several species share dominance. The two most important species are *Eleocharis macrostachya* and *Carex nebrascensis* (Table 5). The community is restricted to the eastern side of the lake extending from near White Lake in Goshen Bay to the Jordan River, but is best developed in Benjamin's Slough and Provo Bay. The major component species appear to distribute themselves in predictable ways in space—as subdominants of the community. *Scirpus validus* for example, is often found in nearly pure stands surrounded by mixed zones of *Eleochraris macrostachya* and *Carex nebraskensis*. These latter species generally give way to areas dominated by *Distichlis stricta*. The relationship appears to be associated with a water gradient in which moisture increases as one moves toward areas dominated by *Scirpus validus* (Coombs 1970). Again one sees local areas dominated by single species that reproduce vigorously by asexual processes.

Grass-Rush-Sedge Meadows

The grass-rush-sedge meadows inhabit the largest area of any of the semiaquatic herbaceous communities described thus far. They are situated geographically much like the spikerush-bulrush meadows, but tend to differ in at least the following ways: (1) although seasonally saturated the excess water has generally drained away by late spring, (2) the soils generally are less peaty, and (3) the soils are often slightly to moderately saline.

This community shows the greatest internal variation and as a result exhibits the highest mean diversity value (Table 3), which is exceeded only by the annual herbaceous communities. The community averaged 18 species per study unit and is the only community dominated by grass (Table 6). Of the 8 most important species, 6 are considered to be salt tolerant. The community is extensive (found throughout the study area) and often occupies sites lying between upland shrub types and the communities already described. There is a great deal of subdominant variation within the type that appears to reflect patterns of asexual reproduction on the one hand and islands of local habitat variation on the other (i.e., pockets of peat loam soil dominated by *Carex nebraskensis*, etc.). Again, the major dominants and subdominants segre-

gate along a moisture gradient. The sedges (*Scirpus americanus*, *Eleocharis macrostachya*, and *Carex nebraskensis*) tend to be dominant on those areas of seasonal inundation, and the grasses (*Distichlis stricta*, *Hordeum jubatum*, and *Sporobolus aeroides*) tend to dominate the higher dryer areas.

Lowland Woody Communities

The lowland woody community is a broadly scattered type occupying a variety of disjunct sites about the lake. It is among the three most extensive communities surrounding the lake and is found most often in seasonally submerged sites often near flowing streams. The soils are predominantly mineral (sandy to sandy clay loams) with varying degrees of incorporated organic matter. The community averaged only 9 species per stand (Table 7) and yielded one of the lowest diversity indices (Table 3). Of the woody dominants listed, 3 are shrubs and 2 are trees. There are two layers in the community, the tree-shrub overstory and a grass-annual or aquatic herb understory. The aquatic herbaceous understory is important only in areas where willows are dominant. There is a high degree of subdominant variation and internal heterogeneity in the community. However, in this case, as opposed to previous described types, the majority of the variation is due to habitat differences rather than asexual reproductive patterns.

Tamarix ramosissima and *Elaeagnus angustifolia*, two of the most important species listed (Table 7), are exotic invaders. Since they occur in the overstory and since *T. ramosissima* is the most widely distributed plant in the type, it appears that this type has been more extensively modified by human activities than any other community considered here. Coombs (1970) considered both species to be increasing and suggested that much of the woodland community is in various stages of recovery from disturbance. If his evaluation is accurate, it appears that the woodland community will undergo a great deal of change in the future.

Saline Terrestrial Community

The saline terrestrial community is the most geographically restricted type discussed thus far. It is essentially confined to Benjamin's Slough, Goshen Bay, and surrounding areas. The soils vary from sandy clay loams to heavy clays and are generally poorly drained and alkaline or saline in nature. Soil erosion is often evident and disturbance from several sources is generally apparent. Salt content in the soil varies greatly in both lateral and vertical space. Variation in salinity combines with variation in soil moisture and local topography to produce small scale heterogeneity in the vegetation. The soils in many areas are seasonally wet, but the communities are not required to develop under water.

Small drainage basins are scattered throughout the type and act as receptacles of spring runoff. As the trapped water evaporates from these catchment basins, salts and other materials carried there by the water are left behind. Salt pans or playas develop in such areas. It is around such playa areas that a majority of the vegetational variation is found. This variation is accounted for by concentric rings of vegetation that surround the playas. Terrestrial saline communities are low in species diversity (Table 3) and average only five species per stand (Table 8). Of the dominants listed, all are salt tolerant and two (i.e. *Kochia americana* and *Suaeda nigra*) are considered to be disturbance indicators (Coombs 1970).

Annual Herbaceous Communities

The annual herbaceous type is a conglomeration of several terrestrial communities that occupy waste places around the lake. These areas often have little in common and exhibit high variability in environment and species composition. Because of great environmental variability and regular disturbance, such as along beaches, seasonally inundated islands, and areas heavily impacted by the activities of man, the communities often remain in early seral stages of succession. This is evidenced by the fact that most of the dominant species (Table 9) are of the annual life form, a life-style that permits plants to complete their life cycle in a few months. Since variation is great and conditions change from year to year, patterns in species dominance also fluctuate annually. Stability will only come to these communities as environmental predictability increases.

Ecological Relationships

Total Cover

Total cover in the communities surrounding Utah Lake varies from 9.8 percent in the pondweed sites to 76.6 percent in the Grass-rush-sedge meadows (Table 3). Observed differences appear to be related to variations in moisture (Fig. 3). As seen in Figure 3, the largest cover values occur midway along the moisture gradient in communities that tend to exhibit the most favorable soil moisture regimes. When there is either too much moisture (year-round inundation) or too little moisture (dry upland sites), fewer plants appear to perform well, thus lowering cover values in these areas.

Asexual Reproduction

As previously suggested, much of the subcommunity variation with the aquatic and semiaquatic communities of Utah Lake can be related to asexual reproduction by dominant species. This seems especially true in those communities that are continuously or seasonally inundated for long periods. Figure 4 illustrates this relationship. Communities having dominant species that reproduce asexually are also those communities common to the wet end of the moisture gradient. This being the case, it appears that those habitats with the most uniform moisture conditions tend to select for species capable of asexual reproduction and against species incapable of such reproduction methods.

Intracommunity Similarity

Earlier in this paper reference has been made of the subcommunity (within) variations in each of the seven major community types. Such internal variations can be measured with similarity indices. I have computed a similarity index matrix (Runzicka 1958) utilizing all stands in each community. Thus, the similarity of each stand with all other stands of a community is obtained. All similarity indices in each community matrix is finally averaged to obtain a mean and standard deviation for internal similarity of each community type. The larger the value the more internally similar is the community; conversely, the lower the value the greater the internal variability. Variation in intracommunity similarity is plotted against variation in available moisture for growth in Figure 5. Intracommunity variation is seen to increase as moisture variability increases. This indicates that as habitat predictability decreases, the composition of communities occupying such habitats also becomes more variable and less recognizable as distinct entities.

Life Forms

The relationship of plant life forms to environmental factors has been the concern of

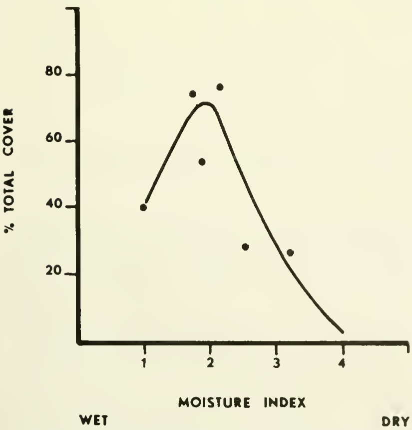

Fig. 3. Total living cover in the Utah Lake communities in relationship to changing moisture conditions.

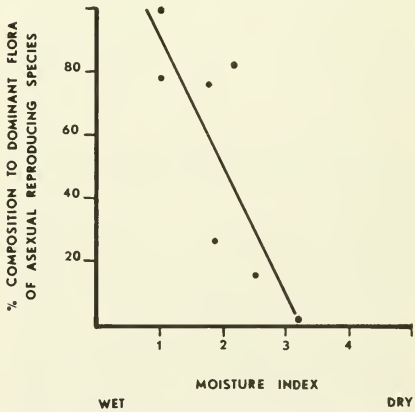

Fig. 4. Importance of asexual reproducing species in the Utah Lake communities as moisture becomes less available.

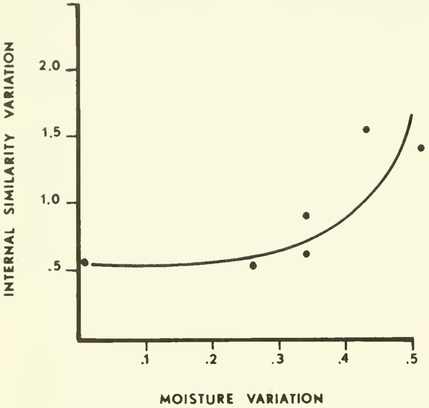

Fig. 5. Variation in internal community similarity as moisture variation increases.

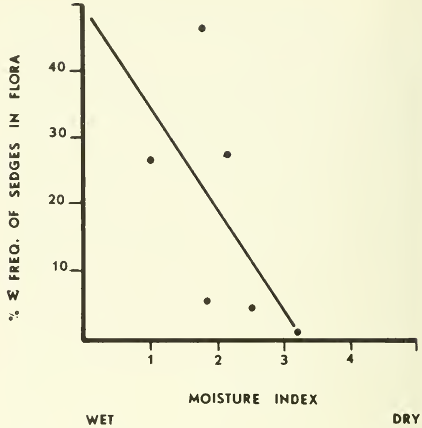

Fig. 7. Importance of sedges in Utah Lake communities in relationship to changing moisture conditions.

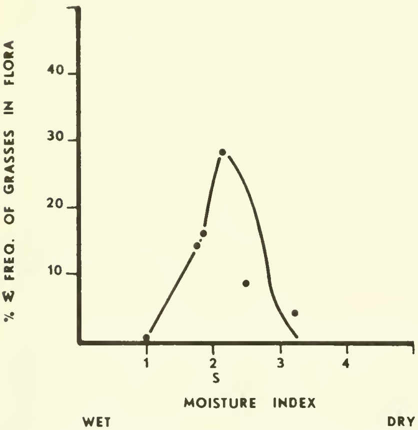

Fig. 6. Importance of grasses in the Utah Lake communities in relationship to changing moisture conditions.

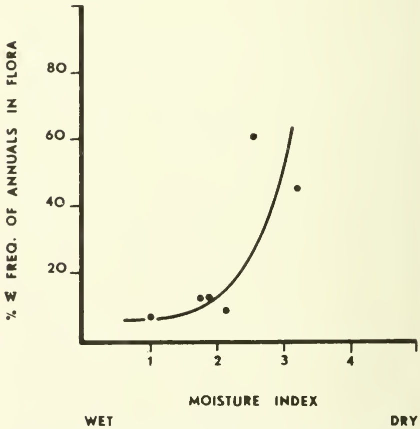

Fig. 8. Importance of annuals in the communities of Utah Lake in relationship to changing moisture conditions.

ecologists for many years. The life form concept was useful in this paper in delimiting community types (i.e., grass-rush-sedge meadows, lowland woody communities, or annual herbaceous communities). The concept also helps relate environmental pattern to plant response in the habitat complex of Utah Lake (Table 3, Figs. 6–10). The data demonstrate that some of the life form classes exhibit rather distinct responses to moisture patterns around the lake. Grasses, for example, do best in habitats with moisture regimes midway along the gradient (Fig. 6). In contrast, the sedges are most abundant at the higher moisture levels (Fig. 7). Annuals reach their greatest importance in the driest habitats (Fig. 8). With respect to annuals, the relationships depicted by Figures 9 and 10 are also of interest. As shown, the annual life form does especially well in habitats that are open, low in cover, and support a good deal of exposed soil. In such areas, interspecific competition

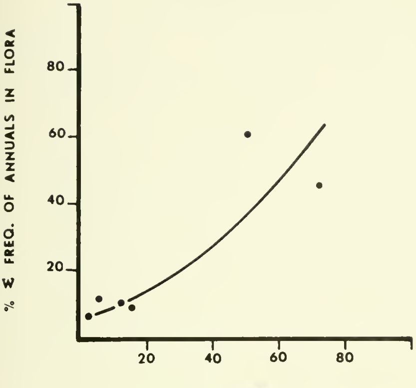

Fig. 9. Importance of annuals in the communities of Utah Lake in relationship to percent exposed surface area.

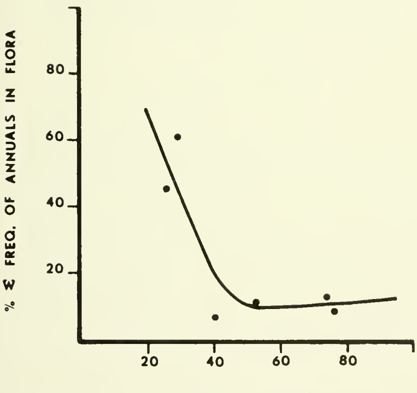

Fig. 10. Importance of annuals in the communities of Utah Lake in relationship to total living cover.

is low, thus giving species which by life-style must complete the life cycle in one season the maximum opportunity to do so.

Introduced Exotics

Species distribution patterns vary greatly in nature; however, in many cases the range of a species tends to be confined to a well-defined geographical region. Should a species jump the barriers confining it to its original range and invade another ecosystem else-

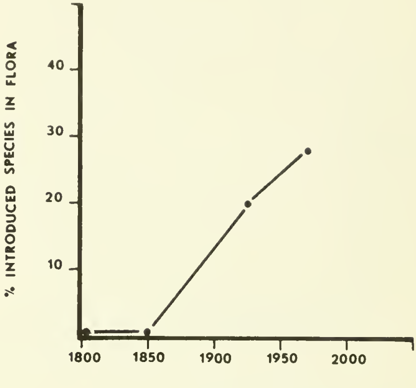

Fig. 11. Increased importance of introduced species in Utah Lake flora since the early 1800s.

where, it becomes a foreign element in that community and is classed as an introduced or exotic species. Historically, many such species have entered the vegetation surrounding Utah Lake (Fig. 11). Cottam (1926) completed the first real quantitative work on the vegetation of Utah Lake. He listed 333 species in the flora, 67 of which (20 percent) were introduced. Coombs (1970) quantitatively studied the same area. He observed 305 species in the flora, 84 of which were introduced (27 percent).

Ecologically, introduced species may (1) invade native ecosystems and cause unexpected consequences of a harmful or disruptive nature, (2) invade and increase the complexity of existent ecosystems and become useful (nondisruptive) components of such communities, (3) become marginally established and exhibit no apparent effect on the original system, or (4) fail to become established. In the case of the communities around Utah Lake, one can find examples of species that fill all the above categories. However, only a few species (i.e., *Tamarix ramosissima, Elaeagnus angustifolia, Bromus tectorum, Trifolium hybridum, Atriplex hortensis, Polygonum lapathifolium,* and *Malva neglecta,* etc.) have become major influences in these natural communities. If the distribution patterns of the introduced species of the communities studied in the interest of habitat

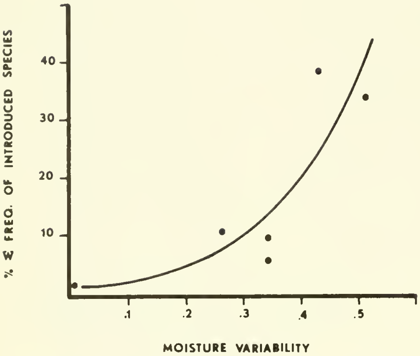

Fig. 12. Importance of introduced species in the communities of Utah Lake as moisture variability increases.

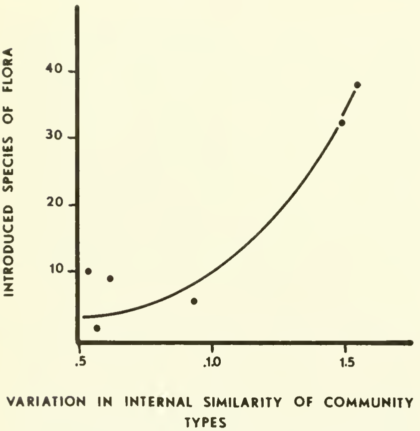

Fig. 13. Importance of introduced species in the Utah Lake communities as internal community similarity increases.

conditions surrounding the lake are considered, two important relationships emerge (Figs. 12 and 13). First, as shown in Figure 12, the introduced species reach their greatest development in those habitats that show the greatest variability in moisture (the most unpredictable environments); and second (Fig. 13), those communities having the greatest internal variation in composition tend to be the most easily invaded. Undoubtedly, such communities have structural gaps that allow a species entering from the outside to become established and compete successfully. These gaps would almost certainly arise as a result of interaction between moisture variability and the resultant effect it has on internal community structure.

TABLE 10. Plant families contributing the majority of species to the flora of Utah Lake.

Family	Percent of species
Asteraceae	16.7
Poaceae	14.5
Cyperaceae	6.3
Chenopodiaceae	5.9
Cruciferae	5.9
Leguminosae	3.9
Polygonaceae	2.9
Rosaceae	2.9
Labiatae	2.5
Salicaceae	2.2
Scrophulariaceae	2.2
Onagraceae	2.0
Total	67.9

Floristic Relationships

A total of 483 species of vascular plants, representing 275 genera, and 74 families was observed and/or found recorded as belonging to the plant communities of Utah Lake. Of these, 67.9 percent belonged to 12 plant families (Table 10). The ecological or phytogeographical significance of the dominance of these families (Table 10) is not known, but further investigations along such lines should hold great interest.

ACERACEAE
Acer grandidentatum Nutt.
Acer negundo L.

AIZOACEAE
Sesuvium verrucosum Raf.

ALISMATACEAE
Alisma triviale Pursh
Sagittaria cuneata Sheld.

AMARANTHACEAE
Amaranthus graecizans L.
Amaranthus retroflexus L.

ANACARDIACEAE
Rhus radicans L.
Rhus trilobata Nutt.

APOCYNACEAE
Apocynum cannabinum L. var. *glaberrimum* A.DC.

ASCLEPIADACEAE
Asclepias incarnata L.
Asclepias speciosa Torr.

ASTERACEAE
Achillea millefolium L.
Ambrosia artemisiifolia L.
Ambrosia psilostachya DC.
Anthemis cotula L.
Arctium minus Schk.
Artemisia absinthium L.
Artemisia dracunculus L.
Artemisia ludoviciana Nutt.
Artemisia spinescens D.C. Eaton
Artemisia tridentata Nutt.
Aster brachyactis Blake
Aster chilensis Nees ssp. *adscendens* (Lindl.) Cronq.
Aster eatonii (A. Gray) Howell
Aster frondosus (Nutt.) Torr. & Gray
Aster perelegans A. Nels. & Macbr.
Balsamorhiza hookeri Nutt.
Bidens cernua L.
Bidens frondosa L.
Chaenactis douglasii H. & A.
Chrysopsis villosa (Pursh) Nutt. var. *foliosa* (Nutt.) D.C. Eaton
Chrysothamnus nauseosus (Pall.) Britt.
Chrysothamnus viscidiflorus (Hook.) Nutt.
Cichorium intybus L.
Cirsium arvense (L.) Scop.
Cirisium foliosum (Hook.) DC.
Cirsium undulatum (Nutt.) Spreng.
Cirsium vulgare (Savi) Airy-Shaw
Conyza candensis (L.) Cronq.
Crepis modocensis Greene
Crepis runcinata (James) Torr. & Gray
Erigeron bellidiastrum var. *typicus* Cronq.
Erigeron divergens Torr. & Gray
Erigeron glabellus Nutt.
Erigeron lonchophyllus Hook.
Eupatorium maculatum L.
Franseria acanthicarpa (Hook.) Cov.
Gnaphalium chilense Spreng.
Gnaphalium palustre Nutt.
Grendelia squarrosa (Pursh) Donal
Haplopappus lanceolatus (Hook.) Torr. & Gray
Haplopappus watsoni A. Gray
Helenium autumnale D.C. Eaton
Helianthus annuus L.
Helianthus nuttallii Torr. & Gray
Helianthus petiolaris Nutt.
Hieracium gracile Hook.
Hymenoxys acaulis (Pursh) Parker
Inula helenium L.
Iva axillaris Pursh
Iva xanthifolia Nutt.
Lactuca pulchella (Pursh) DC.
Lactuca scariola L.
Laphamia stansburii A. Gray
Layia glandulosa (Hook.) Hook. & Arn.
Lygodesmia grandiflora (Nutt.) Torr. & Gray
Machaeranthera tanacetifolia (HBK.) Ness
Matricaria matricarioides (Less.) Porter
Senecio hydrophilus Nutt.
Senecio uintahensis (A. Nels.) Greene
Solidago canadensis L.
Solidago occidentalis (Nutt.) Torr. & Gray
Sonchus arvensis L.
Sonchus asper (L.) Hill
Stephanomeria pauciflora (Torr.) Nutt.
Tanacetum vulgare L.
Taraxacum officinale Weber
Tetradymia glabrata A. Gray
Tetradymia spinosa Hook. & Arn.
Townsendia florifer (Hook.) A. Gray
Townsendia strigosa Nutt.
Tragopogon dubius Scop.
Tragopogon porrifolius L.
Viguiera ciliata (Robins. & Greenm.) Blake
Viguiera multiflora (Nutt.) Blake
Wyethia amplexicaulis (Nutt.) Nutt.
Xanthium strumarium L.
Xanthocephalum sarothrae (Pursh) Shinners

BETULACEAE
Alnus tenuifolia Nutt.
Betula occidentalis Hook.

BORAGINACEAE
Cryptantha flavoculata (A. Nels.) Payson
Cryptantha nana (Eastw.) Payson
Cynoglossum officinalis L.
Heliotropium curassavicum L.
Lappula redowskii (Hornem.) Greene
Lithospermum ruderale Doug. ex Lehm.
Plagiobothrys scouleri (Hook. & Arn.) I.M.

CACTACEAE
Echinocactus simpsonii Engelm.
Echinocereus triglochidiatus Engelm. var. melanacanthus (Engelm.) L. Benson
Opuntia fragilis (Nutt.) Haw.
Opuntia polycantha Haw.

CAPPARIDACEAE
Cleome lutea Hook.
Cleome serrulata Pursh
Polanisia dodecandra (L.) DC.

CAPRIFOLIACEAE
Lonicera involucrata (Rich.) Banks

CARYOPHYLLACEAE
Cerastium vulgatum L.
Saponaria officinalis L.
Spergularia marina (L.) Griseb.

CERATOPHYLLACEAE
Ceratophyllum demersum L.

CHENOPODIACEAE
Allenrolfea occidentalis (S. Wats.) Kuntze
Atriplex confertifolia (Torr. & Frem.) S. Wats
Atriplex heterosperma Bunge
Atriplex hortensis L.

Atriplex patula var. *hastata* (L.) A. Gray
Atriplex tridentata Kuntze
Ceratoides lanata (Pursh) J. T. Howell
Chenopodium album L.
Chenopodium chenopodiodes (L.) Aellen
Chenopodium fremontii S. Wats.
Chenopodium gigantospermum Aellen
Chenopodium glaucum L.
Chenopodium leptophyllum Nutt.
Chenopodium murale L.
Chenopodium watsoni A. Nels.
Corispermum villosum Rydb.
Echinopsilon hyssopifolium (Pall.) Moq.
Grayia spinosa (Hook.) Moq.
Hologeton glomeratus (Bieb.) Mey.
Kochia americana S. Wats.
Kochia scoparia (L.) Schard.
Monolepis nuttalliana (Schult.) Greene
Salicornia pacifica Standl.
Salicornia rubra A. Nels.
Salsola iberica Senner & Pan.
Sarcobatus vermiculatus (Hook.) Torr.
Suaeda depressa (Pursh) S. Wats.
Suaeda fruticosa (L.) Forsk.
Suaeda nigra (Raf.) J. F. Macbride
Suaeda occidentalis S. Wats.

CONVOLVULACEAE
Convolvulus arvensis L.
Convolvulus sepium L.
Cressa truxillensis H.B.K.
Cuscuta salina Engelm.

CORNACEAE
Cornus stolonifera Michx.

CRUCIFERAE
Arabis glabra (L.) Bernh.
Arabis holboellii Hornem.
Brassica campestris L.
Brassica kaber (D.C.) Wheeler var. *pinnatifida*
Brassica nigra (L.) Koch
Camelina microcarpa Andrz.
Capsella bursa-pastoris (L.) Medic.
Cardamine pennsylvanica Muhl. ex Willd.
Cardaria draba (L.) Desv.
Conringia orientalis (L.) Dumort
Descurainia pinnata (Walt.) Britt.
Descurainia sophia (L.) Webb.
Erysimum capitatum (Dougl.) Greene
Erysimum inconspicuum (S. Wats.) Mac M.
Erysimum repandum L.
Hutchinsia procumbens (L.) Desv.
Lepidium densiflorum Schrad.
Lepidium densiflorum var. *ramosum* (A. Nels.) Thell.
Lepidium montanum Nutt.
Lepidium perfoliatum L.
Lepidium virginicum L.
Malcolmia africana (L.) R. Br.
Nasturtium officinale R. Br. in Ait.
Physaria australis (Payson) Rollins
Rorippa islandica (oed.) Borbas
Sisymbrium altissimum L.
Stanleyella wrightii (A. Gray) Rydb.
Streptanthus cordatus Nutt. ex Torr. & Gray
Thelypodium sagittatum (Nutt.) Endl.

CUPRESSACEAE
Juniperus osteosperma (Torr.) Little

CYPERACEAE
Carex aurea Nutt.
Carex aquatilis Wahl.
Carex atherodes Spreng.
Carex lanuginosa Michx.
Carex nebraskensis Dewey
Carex petasata Dewey
Carex praegracilis W. Boott.
Cyperus erythrorhizos Muhl.
Cyperus strigosus L.
Eleocharis acicularis (L.) Roem. & Schult.
Eleocharis bolanderi A. Gray
Eleocharis palustris (L.) Roemer & Scultes
Eleocharis parvula (Roem. and Schult.) Link. var. *coloradensis* (Britton) Beetle
Eleocharis pauciflora (Lightf.) Link.
Eleocharis rostellata Torr.
Fimbristylis spadicea (L.) Vahl.
Scirpus acutus Muhl.
Scirpus americanus Pers.
Scirpus lacustris L.
Scirpus maritimus L.
Scirpus microcarpus Presl.
Scirpus pallidus (Britton) Fernald
Scirpus validus Vahl.

DIPSACACEAE
Dipsacus sylvestris Huds.

ELAEAGNACEAE
Elaeagnus angustifolia L.
Shepherdia argentea (Pursh) Nutt.

EPHEDRACEAE
Ephedra viridis Coville

EQUISETACEAE
Equisetum arvense L.
Equisetum kansanum Schaffn.
Equisetum laevigatum A. Br.
Equisetum palustre L.

EUPHORBIACEAE
Euphorbia glyptosperma Engelm. ex Emory
Euphorbia serpyllifolia Pers.

FUMARIACEAE
Corydalis aurea Willd.

GENTIANACEAE
Centaurium exaltatum (Griseb.) Wight

GERANIACEAE
Erodium cicutarium (L.) L'Her.

HALORAGACEAE
Hippurus vulgaris L.
Myriophyllum spicatum L.

HYDROCHARITACEAE
Elodea canadensis Michx.

IRIDACEAE
Sisyrinchium halophilum Greene

JUNCACEAE
Juncus balticus Willd.
Juncus bufonius L.
Juncus ensifolius Wikstr.
Juncus longistylis Torr.
Juncus torreyi Coville

JUNCAGINACEAE
Triglochin maritima L.

LABIATAE
Lamium amplexicaule L.
Lycopus americanus Muhl. ex Bart.
Lycopus lucidus Turcz.
Marrubium vulgare L.
Mentha arvensis L.
Mentha spicata L.
Moldavica parviflora (Nutt.) Britt.
Nepeta cataria L.
Stachys palustris L.
Teucrium canadense L. var. *occidentale* (A. Gray) McClintock & Epling

LEGUMINOSAE
Astragalus argophyllus Nutt. var. *argophyllus*
Astragalus beckwethii Torr. & Gray
Astragalus canadensis L.
Astragalus convallarius Greene
Astragalus oophorus S. Wats.
Astragalus utahensis (Torr.) Torr. & Gray
Glycyrrhiza lepidota Pursh
Hedysarum boreale Nutt.
Lathyrus brachycalyx Rydb.
Medicago lupulina L.
Medicago sativa L.
Melilotus alba Descr.
Melilotus officinalis (L.) Lam.
Robinia pseudo-acacia L.
Thermopsis montana Nutt.
Trifolium hybridum L.
Trifolium pratense L.
Trifolium repens L.
Vicia americana Muhl. var. *minor* Hook.

LEMNACEAE
Lemna minor L.
Lemna trisulca L.
Lemna valdiviana Phil
Spirodela polyrhiza (L.) Schleid.

LENTIBULARIACEAE
Utricularia minor L.

LILIACEAE
Allium acuminatum Hook.
Asparagus officinalis L.
Smilacina stellata (L.) Desf.

LOASACEAE
Mentzelia albicaulis Dougl. ex Hook.
Mentzelia decapetala (Pursh) Urb. & Gilg.
Mentzelia laevicaulis (Dougl.) Torr. & Gray
Mentzelia multiflora (Nutt.) A. Gray

LYTHRACEAE
Lythrum salicaria L.

MALVACEAE
Althaea rosea Cav.
Malva neglecta Wallr.
Sida hederacea (Dougl.) Torr.
Sidalcea neomexicana A. Grey
Sidalcea oregana (Nutt.) A. Gray
Sphaeralcea coccinea (Pursh) Rydb.
Sphaeralcea grossulariaefolia (H. & A.) Rydb.
Sphaeralcea munroana (Dougl.) Spach

MORACEAE
Morus rubra L.

NYCTAGINACEAE
Abronia salsa Rydb.

NYMPHAECEAE
Nuphar polysepalum Engelm.

OLEACEAE
Fraxinus velutina Torr.

ONAGRACEAE
Epilobium adenocaulon Hausskn.
Epilobium paniculatum Nutt. ex Torr. & Gray
Gaura parviflora Dougl.
Oenothera alyssoides Hook. & Arn.
Oenothera caespitosa Nutt.
Oenothera hookeri Torr. & Gray
Oenothera latifolia (Rydb.) Munz
Oenothera minor (A. Nels.) Munz
Oenothera pallida Lindl.
Oenothera scapoidea Torr. & Gray ssp. *utahensis* Raven

ORCHIDACEAE
Cypripedium calceolus L. var. *pubescens* (Willd.) Cornell
Epipactis gigantea Dougl.
Spiranthes romanzoffiana Cham. & Schl.

OROBANCHACEAE
Orobanche multiflora Nutt.

PAPAVERACEAE
Argemone munita Dur. and Hilg.

PLANTAGINACEAE
Plantago lanceolata L.
Plantago major L.
Plantago patagonica Jacq.

POACEAE
Agropyron cristatum (L.) Gaertn.
Agropyron dasystachyum Scribn. (Hook.)
Agropyron elongatum (Host.) Beauv.

Agropyron intermedium (Host) Beauv.
Agropyron repens (L.) Beauv.
Agropyron smithii Rydb.
Agropyron spicatum (Pursh) Scribn. & Smith
Agropyron trachycaulum (Link) Malte.
Agrostis semiverticillata (Forsk.)
Agrostis stolonifera L.
Alopecurus aequalis Sobol.
Avena fatua L.
Avena sativa L.
Beckmannia syzigachne (Steud.) Fern.
Bromus commutatus Schrad.
Bromus inermis Leyss.
Bromus tectorum L.
Calamagrostis canadensis (Michx.) Beauv.
Calamagrostis neglecta (Ehrh.) Gaertn. Mey & Schreb.
Catabrosa aquatica (L.) Beauv.
Cenchrus tribuloides L.
Dactylis glomerata L.
Deschampsia caespitosa (L.) Beauv.
Distichlis spicata (L.) Green
Echinochloa crusgalli (L.) Beauv.
Elymus canadensis L. Michx.
Elymus cinereus Scribn. & Merr.
Elymus simplex Scribn. & Williams
Elymus tritiocides Buckl.
Elymus virginicus L. var. *submuticus* Hook.
Eragrostis cilianensis (All.) Mosher
Eragrostis hypnoides (Lam.) Britton, Sterns, & Poggenb.
Eragrostis orcuttiana Vasey
Festuca pratensis Huds.
Glyceria grandis S. Wats.
Hordeum brachyantherum Nevski
Hordeum jubatum L.
Hordeum leporinum Link.
Leersia oryzoides (L.) Swantz
Leptochloa fascicularis (Lam.) A. Gray
Lolium multiflorum Lam.
Muhlenbergia asperifolia (Nees & Meyen) Parodi
Oryzopsis hymenoides (R. & S.) Riker
Panicum capillare L.
Panicum capillare L. var. *occidentale* Rydb.
Phalaris arundinacea L.
Phleum pratense L.
Phragmities australis (Cav.) Trin. ex Steudel
Poa annua L.
Poa navadensis Vasey ex Scribn.
Poa pratensis L.
Polypogon monspeliensis (L.) Desf.
Puccinellia nuttalliana (J.A. Schultes) A.S. Hitchc.
Sclerochloa dura (L.) Beauv.
Secale cereale L.
Setaria glauca (L.) Beauv.
Setaria viridis (L.) Beauv.
Sitanion hystrix (Nutt.) J. G. Smith
Sitanion jubatum J. G. Smith
Spartina gracilis Trin.
Sphenopholis obtusata (Michx.) Scribn.
Sporobolus airoides (Torn) Torr.
Sporobolus asper (Michx.) Kunth
Sporobolus cryptandrus (Torr.) A. Gray
Stipa comata Trin. & Rupr.
Triticum aestivum L.
Vulpia octoflora (Walter) Rydb.

POLEMONIACEAE
Collomia linearis Nutt.
Gilia aggregata (Pursh) Spreng.
Gilia inconspicua (Smith) Sweet
Gilia leptomeria A. Gray
Gilia tenerrima A. Gray
Phlox austromontana Coville
Phlox longifolia Nutt.
Polemonium micranthum Benth.
Polemonium occidentale Greene

POLYGONACEAE
Eriogonum effusum Nutt.
Eriogonum racemosum Nutt.
Eriogonum umbellatum Torr.
Polygonum amphibium L.
Polygonum aviculare L.
Polygonum coccineum Muhl. ex Willd.
Polygonum convolvulus L.
Polygonum lapathifolium L.
Polygonum pennsylvanicum L.
Polygonum persicaria L.
Polygonum ramosissimum Michx.
Rumex crispus L.
Rumex fueginus Phil.
Rumex venosus Pursh

PORTULACACEAE
Portulaca oleracea L.

POTAMOGETONACEAE
Potamogeton crispus L.
Potomogeton filiformis Pers.
Potamogeton foliosus Raf.
Potamogeton nodosus Poir. ex Lam.
Potamogeton pectinatus L.
Potamogeton praelongus Wulf.

PRIMULACEAE
Dodecatheon pulchellum (Raf.) Merrill
Glaux maritima L.
Steironema ciliatum (L.) Raf.

RANUNCULACEAE
Delphinium andersoni A. Gray
Ranunculus acris L.
Ranunculus aquatilis L. *capillaceus* (Thuill.) DC.
Ranunculus circinatus Sibth.
Ranunculus cymbalaria Pursh
Ranunculus macounii Britton
Ranunculus oreogenes Greene
Ranunculus testiculatus Crantz

ROSACEAE
Amelanchier alnifolia (Nutt.) Nutt.
Amelanchier utahensis Koehne
Cowania mexicana D. Don
Crataegus douglasii Lindl. var. *rivularis* (Nutt.) Sarg.
Potentilla anserina L.
Potentilla biennis Greene
Potentilla glandulosa Lindl.
Potentilla gracilis Dougl. var. *elmeri* (Rydb.) Jeps.
Potentilla paradoxa Nutt.
Prunus americana Marsh
Prunus virginiana L. var. *melanocarpa* (A. Nels.) Sarg.

Purshia tridentata (Pursh) DC.
Rosa nutkana Presl.
Rosa woodsii Lindl.

Rubiaceae
Galium trifidum L.

Ruppiaceae
Ruppia maritima L.

Salicaceae
Populus alba L.
Populus angustifolia James
Populus deltoides Bartr.
Populus fremontii S. Wats.
Populus nigra L. var. *italica* Muenchh.
Populus trichocarpa Torr. & Gray
Salix amygdaloides Anders.
Salix exigua Nutt.
Salix fragilis L.
Salix lasiandra Benth.
Salix rigida Muhl.

Salviniaceae
Azolla caroliniana Willd.
Salvinia rotundifolia Willd.

Santalaceae
Comandra pallida A. DC.

Saxifragaceae
Heuchera parvifolia Nutt. ex Torr. & Gray
Ribes aureum Pursh

Scrophulariaceae
Castilleja chromosa A. Nels.
Castilleja exilis A. Nels.
Castilleja minor (A. Gray) A. Gray
Collinsia grandiflora Dougl.
Cordylanthus canescens A. Gray
Mimulus glabratus HBK
Mimulus guttatus DC.
Penstemon humilis Nutt. ex A. Gray
Verbascum thapsus L.
Veronica americana Schwein
Veronica anagallis-aquatica L.
Veronica hederaefolia L.
Veronica peregrina L.

Solanaceae
Lycium halimifolium Mill.
Physalis longifolia Nutt.
Solanum dulcamara L.
Solanum nigrum L.
Solanum triflorum Nutt.

Sparganiaceae
Sparganium emersum Rehmann
Sparganium eurycarpum Engelm.

Tamaricaceae
Tamarix ramosissima Ledeb.

Thypaceae
Typha angustifolia L.
Typha latifolia L.

Ulmaceae
Celtis reticulata Torr.
Ulmus americana L.
Ulmus pumila L.

Umbelliferae
Berula erecta (Huds.) Coville
Cicuta douglasii (DC.) Coult. & Rose
Conium maculatum L.
Pastinaca sativa L.
Sium suave Walt.

Urticaceae
Urtica dioica L. var *procera* (Muhl.) Wedd.
Urtica serra Blume

Verbenaceae
Verbena bracteata Lag. and Rodr.
Verbena hastata L.
Verbena stricta Vent.

Violaceae
Viola nephrophylla Greene

Zannichelliaceae
Zannichellia palustris L.

Zygophyllaceae
Tribulus terrestris L.

Species included in the literature as being present in the Utah Lake flora but for which there is not any evidence that such is the case.

Amaranthus lividus L.
Camelina sativa (L.) Crantz.
Carex aperta Boott.
Cenchrus tribuloides L.
Erigeron annuus (L.) Pers.
Gnaphalium occidentalis Nutt.
Lepidium ramosissimum A. Nels.
Mirabilis linearis (Pursh) Heimerl.
Sagittaria graminea Michx.
Scirpus nebraskensis L.

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PHYTOPLANKTON OF UTAH LAKE

Samuel R. Rushforth,[1] Larry L. St. Clair,[1] Judith A. Grimes,[1] and Mark C. Whiting[1,2]

Abstract.— The plankton flora of Utah Lake includes a total of 295 species to date. This high number of taxa indicates greater diversity than previously suspected. Together with water chemical data it leads us to conclude that Utah Lake is a slightly saline eutrophic system. This conclusion is further substantiated by quantitative data which show very high levels of productivity during late summer and early fall.

Utah Lake is a shallow, eutrophic, slightly saline desert lake located in central Utah (Map 1). The deepest portion of the lake is no more than 4.2 m and the average depth is 2.8 m (Bingham 1974). The lake covers an area of 388 km² (Brown 1968). The water is highly turbid with Secchi disk readings averaging 24 cm and ranging from less than 12 to 50 cm. The lake is often classified as highly eutrophic due to the turbidity and dense algal blooms that occur essentially every year in the late summer and early fall.

The lake basin receives inflow from numerous mineral springs within and around the periphery of the lake. As a result, the water has a high carbonate and sulfate content. The total dissolved solids in the lake varied between 795 and 1650 mg/l from 1961 to 1978. At the present conductivity level (average 1400 μm) of the lake and assuming the same ions are present, the total dissolved solids range from 700 to 1000 mg/l during typical inflow years and lake levels. Lakes having between 1,000 and 3,000 mg/l of dissolved solids are described by the U.S. Geological Survey (Hem 1970) as being slightly saline.

Preliminary studies of zooplankton were conducted by Tanner (1931) and Hunt (1940), but little significant research has been done since. Likewise, few significant studies of the phytoplankton have been done. Harding (1970, 1971) published two algal lists in which he identified several phytoplankters as being present in the lake. However, his lists are incomplete, and particularly ignore the Bacillariophyta (diatoms).

This study provides a comprehensive list of all algae collected from the water column through 1978, together with descriptions of the major algal species present in Utah Lake. We are aware that many of these species, particularly many of the diatoms, are not true plankters. Even so, they represent important members of the floating algal assemblage and thus are reported herein.

Methods

Phytoplankton samples were collected at regular intervals during the summer of 1974 at 14 stations along three permanent transects (Map 1). The transects were chosen to represent three supposed subenvironments within the lake. Stations were established at approximately equal intervals along the transects. Each station was marked with buoys, and shore triangulation points were recorded so that the point could be relocated on each successive sampling date. The northern or Geneva transect ran west from the spillway of the settling pond of United States Steel's Geneva Works. It consisted of 5 stations. The middle or Provo Boat Harbor transect also had 5 stations. It ran west from a point just south of the mouth of Provo Riv er and north of Provo Bay. The southern or Goshen Bay transect, with only 4 stations, ran west from Ludlow's sheep barns near Lincoln Beach.

Samples were collected every nine days from 4 June 1974 to 15 August 1974. Sampling was always done in the morning in order to minimize diurnal variability. In addition, samples were collected on a less intensive basis during the spring and summer months of 1975 and 1976 and again with

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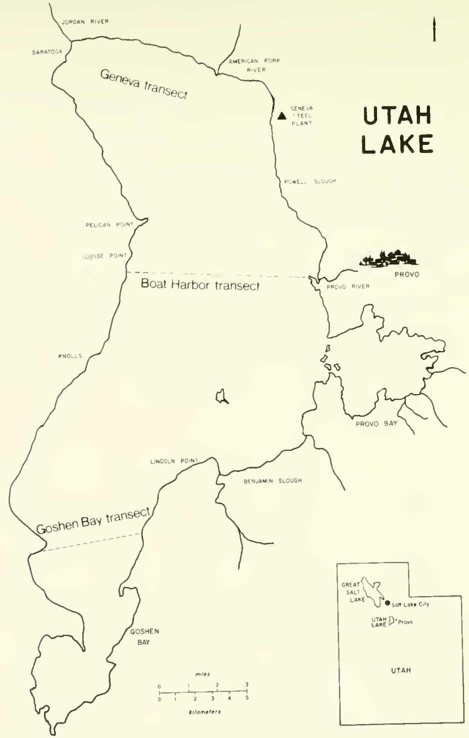
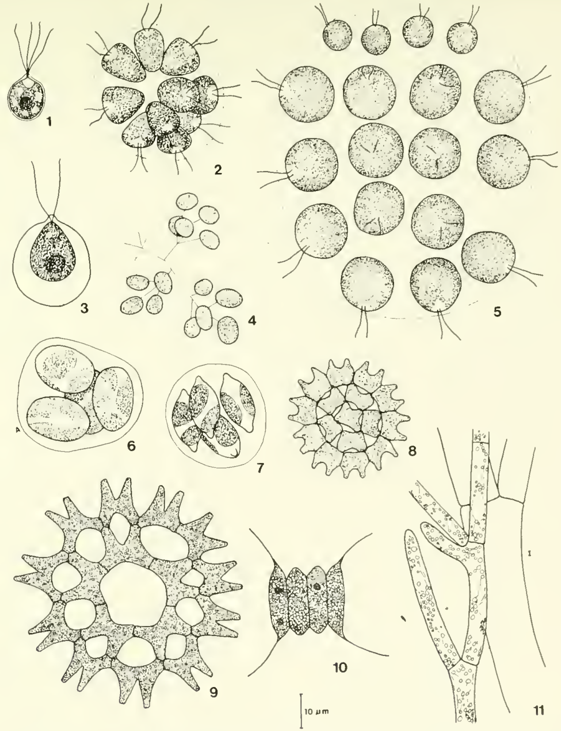


Map 1. Reference map of Utah Lake showing its position within the state, prominent shoreline features, and the location of three transects established within the lake for phytoplankton sampling.



Figs. 1–11: 1, *carteria stellifera*; 2, *Pandorina morum*; 3, *Sphaerellopsis aulata*; 4, *Dictyosphaerium ehrenbergianum*; 5, *Pleodorina illinoisensis*; 6, *Oocystic borgei*; 7, *Oocystis lacustris*; 8, *Pediastrum duplex*; 9, *Pediastrum duplex* var. *gracilimum*; 10, *Scenedesmus quadricauda* var. *longispina*; 11, *Cladophora glomerata*. All figures except Fig. 11 are drawn to the same scale. Scales provided represent 10 μm.

greater intensity during the summer and fall of 1978.

The phytoplankton was sampled by pouring known volumes of water through a 64 µm mesh net. The water was dipped from the lake with a 10-liter bucket. The amount of water poured through the net varied as the summer progressed because the amount of algae in a given volume of water increased during bloom periods. In most cases, algae were identified and counted immediately upon returning to the laboratory, but in all cases within 48 hours of collection.

Laboratory analysis consisted of identifying and counting the algae present in phytoplankton samples. Algal samples were subsampled, the organisms present were identified to species, and the frequency of each organism was recorded. Components of the phytoplankton were first counted in Palmer counting cells at 400X and the numbers of organisms in the original lake water were calculated by multiplication factors. Since diatoms cannot usually be identified to species in wet mount slides, permanent diatom slides were made using Naphrax mounting medium and standard oxidation methods (St. Clair and Rushforth 1976). The diatoms were counted and the relative frequency of each species was calculated.

Results

A total of 295 phytoplankters has been identified from Utah Lake (Table 1). Species described below represent some of those most commonly encountered during our studies. Each is given a brief description and a summary of collection data. In addition, a reference to a complete description of the organism is provided.

Division: Chlorophyta

Order: Volvocales

Carteria stellifera Nygaard (Fig. 1). Plant unicellular; cells spherical to subspherical with slight apical papilla from which the four flagella arise, 10–20 µm in diameter, 12.5–22.5 µm long (Thienemann 1961:95). Abundant at the mouth of the Provo River throughout the summer months and occasionally important locally in other parts of the lake.

Table 1. Phylogenetic list of algae collected from the water column in Utah Lake 1974–1978.

Chlorophyta

Chlorophyceae
- Volvocales
  - Chlamydomonadaceae
    - *Carteria cordiformis* (Carter) Dill
    - *Carteria klebsii* (Dang.) Francé *em.* Troitzkaja
    - *Carteria stellifera* Nygaard
    - *Chlamydomonas altera* Skuja
    - *Chlamydomonas globosa* Snow
    - *Chlamydomonas polypyrenoideum* Prescott
    - *Sphaerellopsis aulata* (Pascher) Gerloff
  - Phacotaceae
    - *Wislouchiella planctonica* Skvortzow
  - Volvocaceae
    - *Pandorina morum* (Muell.) Bory
    - *Pleodorina illinoisensis* Kofoid
- Tetrasporales
  - Palmellaceae
    - *Sphaerocystis schroeteri* Chodat
- Ulotrichales
  - Chaetophoraceae
    - *Stigeoclonium stagnatile* (Hazen) Collins
- Cladophorales
  - Cladophoraceae
    - *Cladophora glomerata* (Lemm.) Kuetzing
- Chlorococcales
  - Micractiniaceae
    - *Micractinium pusillum* Fresenius
  - Dictyosphaeriaceae
    - *Dictyosphaerium ehrenbergianum* Naegeli
  - Characiaceae
    - *Ankyra judayi* (G. M. Smith) Fott.
    - *Schroederia setigera* (Schroeder) Lemmermann
  - Hydrodictyaceae
    - *Pediastrum boryanum* (Turp.) Meneghini
    - *Pediastrum duplex* Meyen
    - *Pediastrum duplex* var. *brachylobum* A. Braun
    - *Pediastrum duplex* var. *clathratum* (A. Braun) Lagerheim
    - *Pediastrum duplex* var. *gracilimum* West & West
    - *Pediastrum simplex* (Meyen) Lemmermann
    - *Pediastrum simplex* var. *duodenarium* (Bailey) Rabenhorst
    - *Pediastrum tetras* (Ehr.) Ralfs
    - *Pediastrum tetras* var. *tetraodon* (Corda) Hansgirg
  - Coelastraceae
    - *Coelastrum microporum* Naegeli
  - Oocystaceae
    - *Ankistrodesmus convolutus* Corda
    - *Ankistrodesmus falcatus* (Corda) Ralfs
    - *Ankistrodesmus falcatus* var. *mirabilis* (West & West) G. S. West
    - *Ankistrodesmus falcatus* var. *stipitatus* (Chod.) Lemmermann
    - *Closteriopsis longissima* var. *tropica* West & West
    - *Kirchneriella lunaris* (Kirch.) Moebius
    - *Lagerheimia longiseta* var. *major* G. M. Smith
    - *Lagerheimia wratislawiensis* Schroeder

Table 1 continued.

Oocystis borgei Snow
Oocystis elliptica W. West
Oocystis gigas Archer
Oocystis gloeocystiformis Borge
Oocystis lacustris Chodat
Oocystis novae-semliae Wille
Oocystis parva West & West
Oocystis pusilla Hansgirg
Oocystis submarina Lagerheim
Quadrigula lacustris (Chod.) G. M. Smith
Selenastrum bibraianum Reinsch
Selenastrum gracile Reinsch
Selenastrum westii G. M. Smith
Treubaria triappendiculata Bernard

Scenedesmaceae
Actinastrum hantzschii Lagerheim
Actinastrum hantzschii var. *fluviatile* Schroeder
Crucigenia guadrata Morren
Crucigenia tetrapedia (Kirch.) West & West
Scenedesmus abundans var. *brevicauda* G. M. Smith
Scenedesmus acuminatus (Lagerheim) Chodat
Scenedesmus bijuga var. *alterans* (Reinsch) Hansgirg
Scenedesmus bijuga var. *flexuosus* Lemmermann
Scenedesmus dimorphus (Turp.) Kuetzing
Scenedesmus longus var. *naegelii* (de Bréb.) G. M. Smith
Scenedesmus opoliensis P. Richter
Scenedesmus perforatus Lemmermann
Scenedesmus quadricauda (Turp.) de Brébisson
Scenedesmus quadricauda var. *longispina* (Chod.) G. M. Smith

Zygnematales
Desmidaceae
Closterium sp.
Staurastrum paradoxum Meyen
Staurastrum tetracerum Ralfs

CHRYSOPHYTA

Xanthophyceae
Tribonematales
Tribonemataceae
Tribonema bombycinium (C. A. Ag.) Derbes & Solier

Chrysophyceae
Chrysomonadales
Ochromonadaceae
Dinobryon bavaricum Imhof
Dinobryon divergens Imhof
Dinobryon sociale var. *americanum* (Brunn.) Bachmann

Mallomonadaceae
Mallomonas acaroides Perty
Mallomonas caudata Iwanoff
Mallomonas pseudocoronata Prescott
Mallomonas tonsurata Teiling

Table 1 continued.

BACILLARIOPHYTA

Bacillariophyceae
Biddulphiales
Biddulphiaceae
Biddulphia laevis Ehrenberg

Chaetoceraceae
Chaetoceros elmorei Boyer

Coscinodiscales
Coscinodiscaceae
Coscinodiscus lacustris Grunow.
Cyclotella antiqua W. Smith
Cyclotella bodanica Eulenstein
Cyclotella kutzingiana Thwaites
Cyclotella meneghiniana Kuetzing
Cyclotella ocellata Pantocsek
Cyclotella stelligera Cleve and Grunow
Melosira granulata (Ehr.) Ralfs
Melosira granulata var. *angustissima* O. Mueller
Melosira italica (Ehr.) Kuetzing
Melosira varians Agardh
Stephanodiscus astrea (Ehr.) Grunow
Stephanodiscus astrea var. *minutula* (Kuetzing) Grunow
Stephanodiscus niagarae Ehrenberg
Thalassiosira sp.

Fragilariales
Fragilariaceae
Asterionella formosa Hassall
Diatoma tenue Agardh
Diatoma tenue var. *elongatum* Lyngbye
Diatoma vulgare Bory
Diatoma vulgare var. *grande* (W. Sm.) Grunow
Fragilaria brevistriata Grunow
Fragilaria brevistriata var. *capitata* Heribaud
Fragilaria brevistriata var. *inflata* (Pant.) Hustedt
Fragilaria construens (Ehr.) Grunow
Fragilaria construens var. *binodis* (Ehr.) Grunow
Fragilaria construens var. *pumila* Grunow
Fragilaria construens var. *venter* (Ehr.) Grunow
Fragilaria crotonensis Kitton
Fragilaria leptostauron (Ehr.) Hustedt
Fragilaria vaucheriae (Kuetz.) Petersen
Hannaea arcus (Ehr.) Patrick
Opheplora martyi Heribaud
Synedra capitata Ehrenberg
Synedra delicatissima var. *angustissima* Grunow
Synedra fasciculata var. *truncata* (Grev.) Patrick
Synedra mazamaensis Sovereign
Synedra rumpens var. *familiaris* (Kuetz.) Grunow
Synedra rumpens var. *fragilarioides* Grunow
Synedra rumpens var. *scotica* Grunow
Synedra tenera W. Smith
Synedra ulna (Nitzsch) Ehrenberg
Synedra ulna var. *contracta* Ostrup

Eunotiales
Eunotiaceae
Eunotia arcus var. *bidens* Grunow

Achnanthales
Achnanthaceae
Achnanthes clevei Grunow
Achnanthes deflexa Reimer

Table 1 continued.

Achnanthes exigua Grunow
Achnanthes hauckiana Grunow
Achnanthes lanceolata (Breb.) Grunow
Achnanthes lanceolata var. *dubia* Grunow
Achnanthes linearis (W. Sm.) Grunow
Achnanthes minutissima Kuetzing
Cocconeis pediculus Ehrenberg
Cocconeis placentula var. *euglypta* (Ehr.) Cleve
Cocconeis placentula var. *lineata* (Ehr.) Van Heurck
Cocconeis diminuta (Pantocsek
Rhoicosphenia curvata (Kuetz.) Grunow
Naviculales
Naviculaceae
Anomoeoneis sphaerophora (Ehr.) Pfitzer
Caloneis amphisbaena (Bory) Cleve
Caloneis bacillum (Grun.) Cleve
Caloneis fenzlioides Cleve-Euler
Caloneis schumanniana (Grunow) Cleve
Diploneis oblongella (Naegeli *ex* Kuetz.) Ross
Diploneis pseudovalis Hustedt
Diploneis smithii var. *dilatata* (M. Perag.) Boyer
Diploneis smithii var. *pumila* (Grun.) Hustedt
Gyrosigma acuminatum (Kuetz.) Rabenhorst
Mastogloia elliptica var. *danseii* (Thwaites) Cleve
Navicula amphibola Cleve
Navicula arvensis Hustedt
Navicula aurora Sovereign
Navicula capitata Ehrenberg
Navicula capitata var. *hungarica* (Grun.) Ross
Navicula circumtexta Meist. *ex* Hustedt
Navicula crucicula (W. Sm.) Donk.
Navicula cryptocephala Kuetzing
Navicula cryptocephala var. *veneta* (Kuetz.) Rabenhorst
Navicula cuspidata (Kuetz.) Kuetzing
Navicula exigua Greg. *ex* Grunow
Navicula exigua var. *capitata* Patrick
Navicula graciloides A. Mayer
Navicula lanceolata (Ag.) Kuetzing
Navicula menisculus var. *upsaliensis* (Grun.) Grunow
Navicula minima Grunow
Navicula minuscula Grunow
Navicula oblonga (Kuetz.) Kuetzing
Navicula pelliculosa (Breb. *ex* Kuetz.) Hilse
Navicula peregrina (Ehr.) Kuetzing
Navicula pupula Kuetzing
Navicula pupula var. *rectangularis* (Greg.) Grunow
Navicula pygmaea Kuetzing
Navicula radiosa Kuetzing
Navicula reinhardtii var. *elliptica* Heribaud
Navicula rhyncocephala Kuetzing
Navicula salinarum Grunow
Navicula salinarum var. *intermedia* (Grun.) Cleve
Navicula scutelloides W. Sm. *ex* Gregory
Navicula secreta var. *apiculata* Patrick
Navicula tenelloides Hustedt
Navicula tripunctata (Muell.) Bory
Navicula tuscula Ehrenberg

Table 1 continued.

Navicula viridula (Kuetz.) Kuetzing em. Van Heurck
Navicula sp.
Neidium iridis (Ehr.) Cleve
Pinnularia borealis var. *rectangularis* Carlson
Pinnularia brebissonii (Kuetz.) Rabenhorst
Pinnularia microstauron (Ehr.) Cleve
Pinnularia viridis (Nitzsch) Ehrenberg
Pleurosigma australe Grunow
Pleurosigma delicatulum W. Smith
Scoliopleura peisonis Grunow
Stauroneis phoenicentron (Nitzsch.) Ehrenberg
Cymbellaceae
Amphora coffeiformis (Agardh) Kuetzing
Amphora ovalis (Kuetz.) Kuetzing
Amphora ovalis var. *affinis* (Kuetz.) Van Heurck *ex* De Toni
Amphora perpusilla (Grun.) Grunow
Amphora veneta Kuetzing
Cymbella affinis Kuetzing
Cymbella cistula (Ehr.) Kirchner
Cymbella cymbiformis Agardh
Cymbella mexicana (Ehr.) Cleve
Cymbella microcephala Grunow
Cymbella minuta var. *silesiaca* (Bleisch *ex*. Rabh.) Reimer
Cymbella muelleri Hustedt
Cymbella prostrata (Berk.) Cleve
Cymbella sinuata Gregory
Cymbella tumida (Breb. *ex* Kuetz.) Van Heurck
Cymbella tumidula Grunow *ex* A. Schmidt
Cymbella sp. 1
Cymbella sp. 2
Gomphonemaceae
Gomphonema angustatum (Kuetz.) Rabenhorst
Gomphonema clevei Fricke
Gomphonema intricatum Kuetzing
Gomphonema olivaceum (Lyngb.) Kuetzing
Gomphonema parvulum Kuetzing
Gomphonema sphaerophorum Ehrenberg
Gomphonema truncatum Ehrenberg
Gomphonema ventricosum Greg.
Entimoneidaceae
Entomoneis alata (Ehr.) Ehrenberg
Plagiotropis vitrea (W. Smith) Grunow
Epithemiales
Epithemiaceae
Denticula elegans Kuetzing
Denticula elegans f. *valida* Pedic.
Epithemia sorex Kuetzing
Epithemia turgida (Ehr.) Kuetzing
Epithemia turgida var. *granulata* (Ehr.) Brun
Epithemia adnata (Kuetz.) Brebisson
Rhopalodia gibba (Ehr.) O. Mueller
Rhopalodia gibba var. *ventricosa* (Kuetz.) H. and M. Peragallo
Rhopalodia gibberula var. *protracta* Grunow
Rhopalodia musculus (Kuetz.) O. Mueller
Nitzschiales
Nitzschiaceae
Bacillaria paradoxa Gmelin
Cylindrotheca gracilis (Breb.) Grunow

Table 1 continued.

Hantzschia amphioxys (Ehr.) Grunow
Hantzschia amphioxys f. *capitata* O. Mueller
Nitzschia acicularis W. Smith
Nitzschia amphibia Grunow
Nitzschia apiculata (Greg.) Grunow
Nitzschia communis Rabenhorst
Nitzschia dissipata (Kuetz.) Grunow
Nitzschia filiformis (W. Smith) Hustedt
Nitzschia fonticola Grunow
Nitzschia frustulum (Kuetz.) Grunow
Nitzschia hantzschiana Rabenhorst
Nitzschia hungarica Grunow
Nitzschia linearis W. Smith
Nitzschia longissima var. *closterium* (W. Smith) Van Heurck
Nitzschia ovalis Arnott
Nitzschia palea (Kuetz.) W. Smith
Nitzschia paleacea Grunow
Nitzschia perminuta Grunow
Nitzschia punctata (W. Sm.) Grunow
Nitzschia sigmoidea (Ehr.) W. Smith
Nitzschia tryblionella Hantzsch
Nitzschia tryblionella var. *debilis* (Arnott) A. Mayer
Nitzschia tryblionella var. *genuina* Grunow
Nitzschia tryblionella var. *levidensis* (W. Sm.) Grunow
Nitzschia tryblionella var. *victoriae* Grunow
Surirellales
Surirellaceae
Camplyodiscus hibernicus Ehrenberg
Cymatopleura elliptica (Breb.) W. Smith
Cymatopleura solea (Breb.) W. Smith
Surirella angusta Kuetzing
Surirella ovalis Brebisson
Surirella ovalis var. *brightwellii* (W. Sm.) Cleve-Euler
Surirella ovata Kuetzing
Surirella striatula Turpin

EUGLENOPHYTA

Euglenophyceae
Euglenales
Euglenaceae
Euglena ehrenbergii Klebs
Euglena gracilis Klebs
Euglena oxyuris Schmarda
Euglena proxima Dangeard
Lepocinclis salina Fritsch
Phacus chloroplastes Prescott
Phacus tortus (Lemm.) Skvortzow
Strombomonas fluviatilis (Lemm.) Deflandre
Trachelomonas crebea Killicott–Deflandre

PYRROPHYTA

Dinophyceae
Peridiniales
Glenodiniaceae
Glenodinium dinobryonis (Woloszynska) Lindemann
Glenodinium penardiforme (Lindemann) Schiller

Table 1 continued.

Certiaceae
Ceratium hirundinella (Muell.) Dujardin

CYANOPHYTA

Myxophyceae
Chroococcales
Chroococcaceae
Anacystis rupestris (Lyngb.) Drouet & Daily
Chroococcus minutus (Kuetz.) Naegeli
Gloeocapsa punctata Naegeli
Gomphospheria aponina Kuetzing
Gomphospheria lacustris Chodat
Holopedium irregulare Lagerheim
Marssoniella elegans Lemmermann
Merismopedia glauca (Ehr.) Naegeli
Microcystis aureginosa Kutz. *em.* Elenkin
Microcystis incerta Lemmermann
Microcystis protocystis Crow
Hormogonales
Oscillatoriaceae
Lyngbya majuscula Harvey
Lyngbya martensiana Meneghini
Oscillatoria angustissima West & West
Oscillatoria articulata Gardner
Oscillatoria subbrevis Schmidle
Oscillatoria tenuis Agardh
Schizothrix lacustris A. Braun *ex* Kuetzing
Nostocaceae
Anabaena flos-aquae (Lyngbye) de Brébisson
Anabaena spiroides var. *crassa* Lemmermann
Aphanizomenon flos-aquae (Lemm.) Ralfs
Nostoc caeruleum Lyngbye

Pandorina morum (Muell.) Bory (Fig. 2). Colony ovate or obovoid, composed of 8–16 cells; cells compactly arranged and enclosed by common gelatinous matrix, compressed with broad anterior end directed outward; chloroplast a single parietal cup; cells about 10 μm in diameter; colony of 16 cells 29–37.5 μm in diameter, 38–40 μm long (Prescott 1962:75). Abundant in plankton from Provo River mouth and Provo Boat Harbor, rare to common in remainder of lake. Small colonies of about eight cells were often almost spherical in shape.

Pleodorina illinoisensis Kofoid (Fig. 5). Colony globose with 16–32 cells, 4 of which are small and vegetative; cells spherical, with 4 to 8 pyrenoids; vegetative cells about 8 μm in diameter; reproductive cells about 15 μm in diameter (Prescott 1962:77). Rare to abundant in plankton samples and especially abundant in samples from Provo River mouth.

Sphaerellopsis aulata (Pascher) Gerloff (Fig. 3). Plant unicellular and free swimming; cells teardrop shaped, widely rounded posteriorly and narrowly rounded anteriorly to acute apex, 10–15 μm in diameter, 15–20 μm long; chloroplast cup shaped and filling entire cell wall; eye spot red and often visible; sheath hyaline and very wide, often with apical papilla where flagella emerge. *Sphaerellopsis* differs from *Chlamydomonas* by its wide sheaths that narrow anteriorly and are not same shape as protoplast (Thienemann, 1961:452). Abundant in Provo River mouth in July and August.

Order: Chlorococcales

Dictyosphaerium ehrenbergianum Naegeli (Fig. 4). Colony spherical to ovoid, cells attached in groups of twos and fours at ends of very fine filaments; cells spherical to ellipsoid, 3–6 μm in diameter, 6–10 μm long; chloroplasts 1–2 parietal cups (Prescott 1962:238). Abundant in plankton samples from lake and Provo River mouth in early June, becoming less important in July and August.

Oocystis borgei Snow (Fig. 6). Plant unicellular or in groups of 2–6 enclosed by old mother cell wall; cells ellipsoid-ovate, with poles broadly rounded and without nodular thickenings; chloroplasts single parietal plates; cells 12–13 μm in diameter, 18–20 μm long; colony of four cells about 38 μm in diameter (Prescott 1962:243). Often the most common *Oocystis* in Utah Lake and common in our plankton samples throughout summer.

Oocystis lacustris Chodat (Fig. 7). Plant unicellular or a colony of four cells; mother cell ovoid or sometimes flattened at poles, about 10 μm in diameter, 17.5 μm long; chloroplasts 1–2; colony of four cells about 28μm long (Prescott 1962:245). Often common in plankton samples throughout lake. Can be distinguished by its definite polar papillae. Prescott (1962) mentioned that this alga is often collected in colonies of two to eight cells.

Pediastrum duplex Meyen (Fig. 8). Colony perforate with lens-shaped spaces between cells; inner cells shaped like short, fat H's; peripheral cells with inner margins more or less straight, outer margins concave with blunt-tipped, tapering processes; cells about 8 μm in diameter; colony with about 100 cells, 63 μm across (Prescott 1962:223). Abundant in early June but soon replaced by *P. duplex* var. *gracilimum*, which Prescott (1962) noted as a growth form of typical plant. Latter found throughout the summer.

Pediastrum duplex var. *gracilimum* West & West (Fig. 9). Colony with large perforations; body of cells narrow, equal in width to processes of peripheral cells; processes not tapering, or only slightly tapering; cells larger than typical plant, up to 25 μm in diameter (Prescott, 1962, p. 224). Rare in June but became more common in July and August.

Scenedesmus quadricauda var. *longispina* (Chod.) G. M. Smith (Fig. 10). Colony of 4–8 cells in one series; cells widely variable in size, 5–13 μm in diameter, 15–27 μm long, oblong-cylindric with lateral walls in full contact with adjacent cells; outer cells with long, curved spine at each pole; inner cells without spines (Prescott 1962:280). Abundant in plankton samples in late July and early August. Resembles S. *opoliensis* but separated on basis of amount of lateral wall contact between adjacent cells. Cells of S. *quadracauda* var. *longispina* in contact with adjacent cells along entire lateral walls.

Order: Cladophorales

Cladophora glomerata (Lemm.) Kuetzing (Fig. 11). Filaments successively and regularly branched, branches usually crowded in outer parts of plant; cells cylindrical; apical cells attenuate slightly to a bluntly rounded end; cells of main axis 75–100 μm in diameter, six to seven times diameter in length; cells in branches 35–50 μm in diameter, three to six times diameter in length (Prescott, 1962:138). Found free-floating after becoming detached from rocks in splash zone along lake shore. This taxon was most important littoral alga in lake.

Division: Chrysophyta

Order: Ochromonadales

Dinobryon divergens Imhof (Fig. 52). Colonies much branched and widely diverging; loricas conical, posterior portion usually bent at an angle; lateral margins diverge then change direction, suddenly becoming convergent, then flare out again at mouth; loricas 7–8 μm in diameter, 32–40 μm long

(Prescott 1962:378). Most common *Dinobryon* species in our study. Most abundant at mouth of Provo River but common in some lake plankton samples.

Division: Bacillariophyta

ORDER: RHIZOSOLENIALES

Cyclotella kutzingiana Thwaites (Fig. 12). Cell diameter 8–13 μm; striae 16–20 in 10 μm (Hustedt 1930:98). Common throughout lake.

Cyclotella meneghiniana Kuetzing (Fig. 13). Cell diameter 10–13 μm; striae 6–9 in 10 μm (Hustedt 1930:100). One of most common species throughout lake.

Melosira granulata (Ehr.) Ralfs (Fig. 14). Cells 12–21 μm long by 7–18 μm wide; striae 6–12 in 10 μm (Hustedt 1930:87). Common throughout lake.

Melosira granulata var. *angustissima* Mueller (Fig. 15). Cells 12–17 μm long by 47 μm wide; striae 6–12 in 10 μm (Hustedt 1930:88). Can be collected in large numbers throughout lake. Together with nominate, probably most frequent and abundant of diatom species.

Melosira italica (Ehr.) Kuetzing (Fig. 16). Cells 12–13 μm long by 14–15 μm width; striae 17–18 in 10 μm (Hustedt 1930:91). Common in some years in the lake.

Melosira varians C. A. Agardh (Fig. 17). Cells 11–20 μm long by 11–14 μm wide (Hustedt 1930:85). Taken in low numbers from sites throughout lake.

ORDER: FRAGILARIALES

Diatoma vulgare Bory (Fig. 23). Cells 34–52 μm long by 11–12 μm wide; costae 5–8 in 10 μm; striae indistinct (Patrick and Reimer 1966:109). Throughout lake in low numbers.

Fragilaria brevistriata var. *inflata* (Pant.) Hustedt (Fig. 18). Cells 12 μm long by 4–5 μm wide; striae 14–17 in 10 μm (Patrick and Reimer 1966:129). Frequent throughout lake.

Fragilaria construens (Ehr.) Grunow (Figs. 19, 21, 22). Cells 9–18 μm long by 5–12 μm wide; striae 11–16 in 10 μm (Patrick and Reimer 1966:125). Quite common in Goshen Bay and midlake areas.

Fragilaria construens var. *venter* (Ehr.) Grunow (Fig. 20). Cells 6–7 μm long by 4–5 μm wide; striae 12 in 10 μm (Patrick and Reimer 1966:126). Common throughout lake.

Fragilaria crotonensis Kitton (Fig. 24). Cells 78–83 μm long by 3–4 μm wide; striae 13–15 in 10 μm (Patrick and Reimer 1966:121). Common at both Goshen and boat harbor areas and at scattered sites throughout south and midlake regions.

Fragilaria vaucheriae (Kuetz.) Petersen (Fig. 26). Cells 6–43 μm long by 4–6 μm wide; striae 11–16 in 10 μm (Patrick and Reimer 1966:120). Often collected abundantly throughout lake. Frustule shape is highly variable.

Asterionella formosa Hassall (Fig. 25). Cells 50–77 μm long by 2–3 μm wide; striae 30 in 10 μm (Patrick and Reimer 1966:159). In moderate numbers throughout entire lake early in spring and summer.

ORDER: ACHNANTHALES

Cocconeis placentula var. *lineata* (Ehr.) Van Heurck (Fig. 28). Cells 15–47 μm long by 10–30 μm wide; pseudoraphe valve striae 18–20 in 10 μm; raphe valve striae 19 in 10 μm (Patrick and Reimer 1966:242). Common in samples throughout lake.

Achnanthes minutissima Kuetzing (Fig. 29, 30). Cells 5–29 μm long by 3–5 μm wide; pseudoraphe and raphe valve striae 22–32 in 10 μm (Patrick and Reimer 1966:253). Common in many samples.

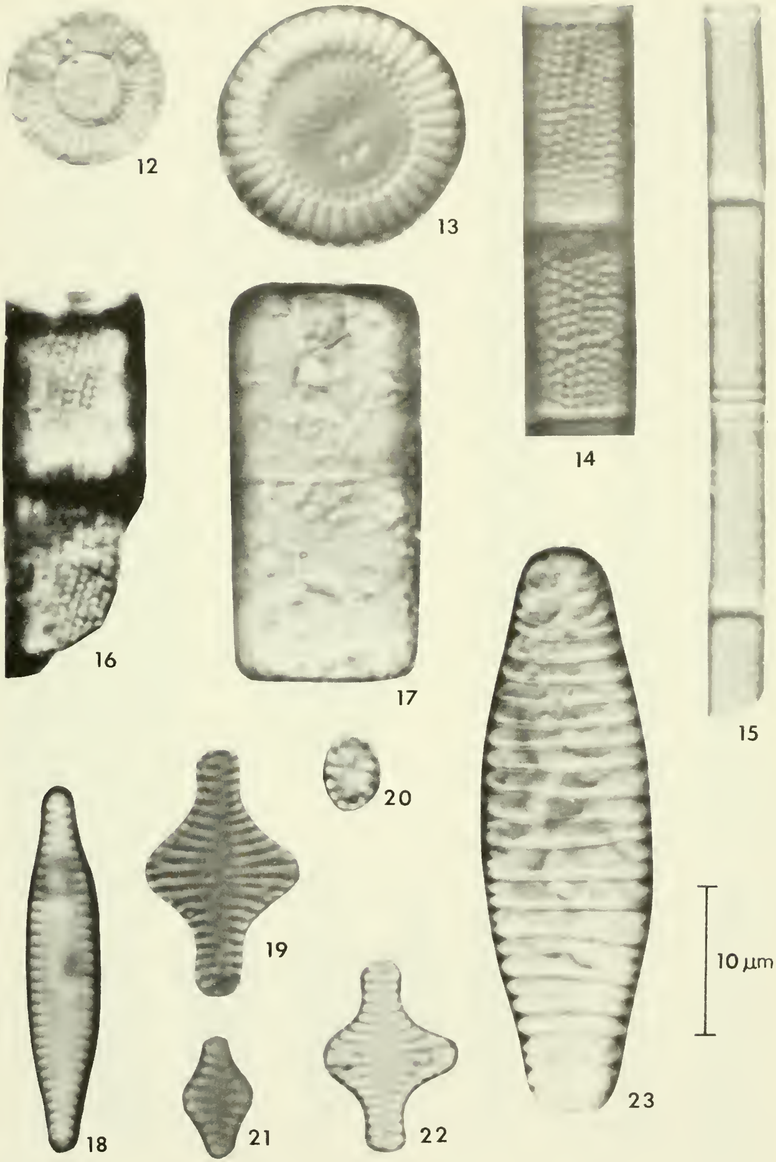
ORDER: NAVICULALES

Gyrosigma acuminatum (Kuetz.) Rabenhorst (Fig. 34). Cells 79–119 μm long by 12–19 μm wide; longitudinal striae 18 in 10 μm; transverse striae 17–18 in 10 μm (Patrick and Reimer 1966:314). Frequent in all parts of lake.

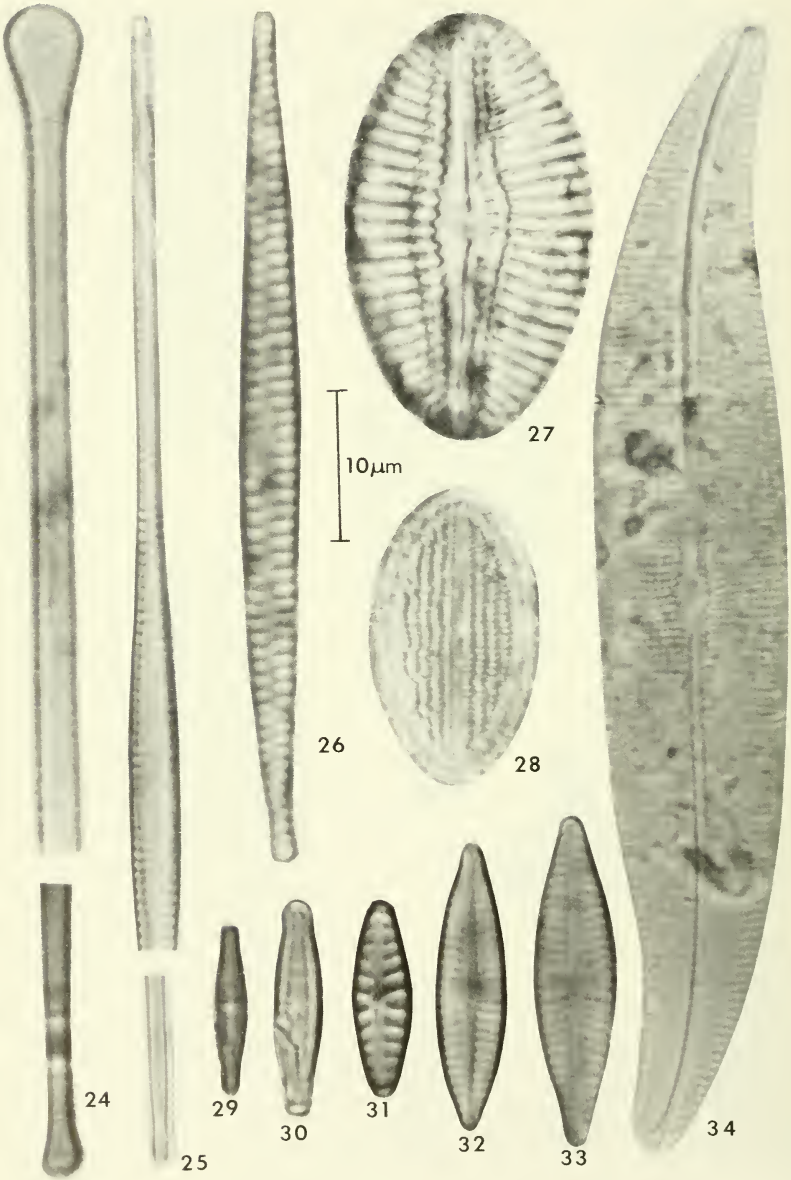
Pleurosigma delicatulum W. Smith. Cells 140–200 μm long by 16–22 μm wide; longitudinal and diagonal striae 19–22 in 10 μm (Patrick and Reimer 1966:336). Taxon characterized by its narrow, sigmoid shape and its angled striae. Rather common in Geneva and Goshen areas of lake, often as an epiphyte.

Diploneis smithii var. *dilatata* (M. Perag.) Boyer (Fig. 27). Cells 25–50 μm long by 16–25 μm wide; costae 8–10 in 10 μm (Patrick and Reimer 1966:411). Common throughout lake.

Navicula capitata var. *hungarica* (Grun.)



Figs. 12–23: 12, *Cyclotella kutzingiana*; 13, *Cyclotella meneghiniana*; 14, *Melosira granulata*; 15, *Melosira granulata* var. *angustissima*; 16, *Melosira italica*; 17, *Melosira varians*; 18, *Fragilaria brevistriata* var. *inflata*; 19, *Fragilaria construens*; 20, *Fragilaria construens* var. *venter*; 21–22, *Fragilaria construens*; 23, *Diatoma vulgare*. All figures are printed to the same scale.



Figs. 24–34: 24, *Asterionella formosa*; 25, *Fragilaria crotonensis*; 26, *Fragilaria vaucheria*; 27, *Diploneis smithii* var. *dilatata*; 28, *Cocconeis placentula* var. *linearis*; 29–30, *Achnanthes minutissima*; 31, *Navicula capitata* var. *hungarica*; 32–33, *Navicula cryptocephala* var. *veneta*; 34, *Gyrosigma acuminatum*. All figures are printed to the same scale.

Ross (Fig. 31). Cells 16–22 μm long by 5–6 μm wide; striae 7–10 in 10 μm (Patrick and Reimer 1966:537). In moderate numbers from all areas of lake.

Navicula cryptocephala var. *veneta* (Kuetz). Rabenhorst (Fig. 32, 33). Cells 10–21 μm long by 4–6 μm wide; striae 13–16 in 10 μm (Patrick and Reimer 1966:504). Frequent at all collecting stations.

Navicula graciloides A. Mayer (Fig. 36). Cells 27–34 μm long by 7–8 μm wide; striae 10–14 in 10 μm (Patrick and Reimer 1966:516). Frequent at all transects throughout collecting seasons. One of most common species in our studies.

Navicula salinarum var. *intermedia* (Grun.) Cleve (Fig. 37). Cells 34–37 μm long by 7–8 μm wide; striae 14–16 in 10 μm (Patrick and Reimer 1966:503). Frequently at many collecting localities.

Navicula tripunctata (Muell.) Bory (Fig. 35). Cells 35–55 μm long by 8–10 μm wide; striae 10–12 in 10 μm (Patrick and Reimer 1966:513). In moderate numbers from many collecting localities.

Caloneis amphisbaena (Bory) Cleve. Cells 68–79 μm long by 22–26 μm wide; striae 13–20 in 10 μm (Patrick and Reimer 1966:579). Frequently throughout lake.

Caloneis fenzlioides Cleve-Euhler (Fig. 38). Cells 86–96 μm long by 25–30 μm wide; striae 11–15 in 10 μm (Cleve-Euler 1955:88). Rather common at many collecting localities.

Amphora ovalis (Kuetz.) Kuetzing (Fig. 43). Cells 30–73 μm long by 6–15 μm wide; ventral striae 10–13 in 10 μm; dorsal striae 9–12 in 10 μm (Patrick and Reimer 1975:68). Abundant at most collecting sites throughout our studies.

Amphora ovalis var. *affinis* (Kuetz.) Van Heurck *ex* De Toni (Fig. 49). Cells 11–35 μm long by 7–10 μm wide; ventral striae 12–16 in 10 μm; dorsal striae 13–16 in 10 μm (Patrick and Reimer 1975:69). Taxon distinguished from nominate variety by its smaller size and rectangular central area. Common throughout lake.

Cymbella affinis Kuetzing (Fig. 44). Cells 27–47 μm long by 9–15 μm wide; ventral striae 9–11 in 10 μm; dorsal striae 10–12 in 10 μm (Patrick and Reimer 1975:57). Common throughout lake.

Cymbella prostrata (Berk.) Cleve (Fig. 46). Cells 28–55 μm long by 10–24 μm wide; ventral striae 7–9 in 10 μm; dorsal striae 8–11 in 10 μm (Patrick and Reimer 1975:40). Common only in northern part of lake.

Cymbella minuta var. *silesiaca* (Bleisch *ex* Rabh.) Reimer (Fig. 51). Cells 25–34 μm long by 10–12 μm wide; ventral striae 9 in 10 μm; dorsal striae 9–14 in 10 μm (Patrick and Reimer 1975:49). Very widespread and often common throughout lake.

Gomphonema angustatum (Kuetz.) Rabenhorst (Fig. 42). Cells 14–38 μm long by 6–7 μm wide; striae 11–16 in 10 μm (Patrick and Reimer 1975:125). Common throughout lake.

Gomphonema intricatum Kuetzing (Fig. 40). Cells 31–70 μm long by 7–12 μm wide; striae 10–13 in 10 μm (Patrick and Reimer 1975:134). Frequent at most collecting localities.

Gomphonema olivaceum (Lyngb.) Kuetzing (Fig. 41). Cells 12–36 μm long by 6–8 μm wide; striae 10–13 in 10 μm (Patrick and Reimer 1975:139). Common in all parts of lake.

Gomphonema ventricosum Gregory (Fig. 39). Cells 33–50 μm long by 9–11 μm wide; striae 12–13 in 10 μm (Patrick and Reimer 1975:137). Occasionally common in some samples.

ORDER: NITZSCHIALES

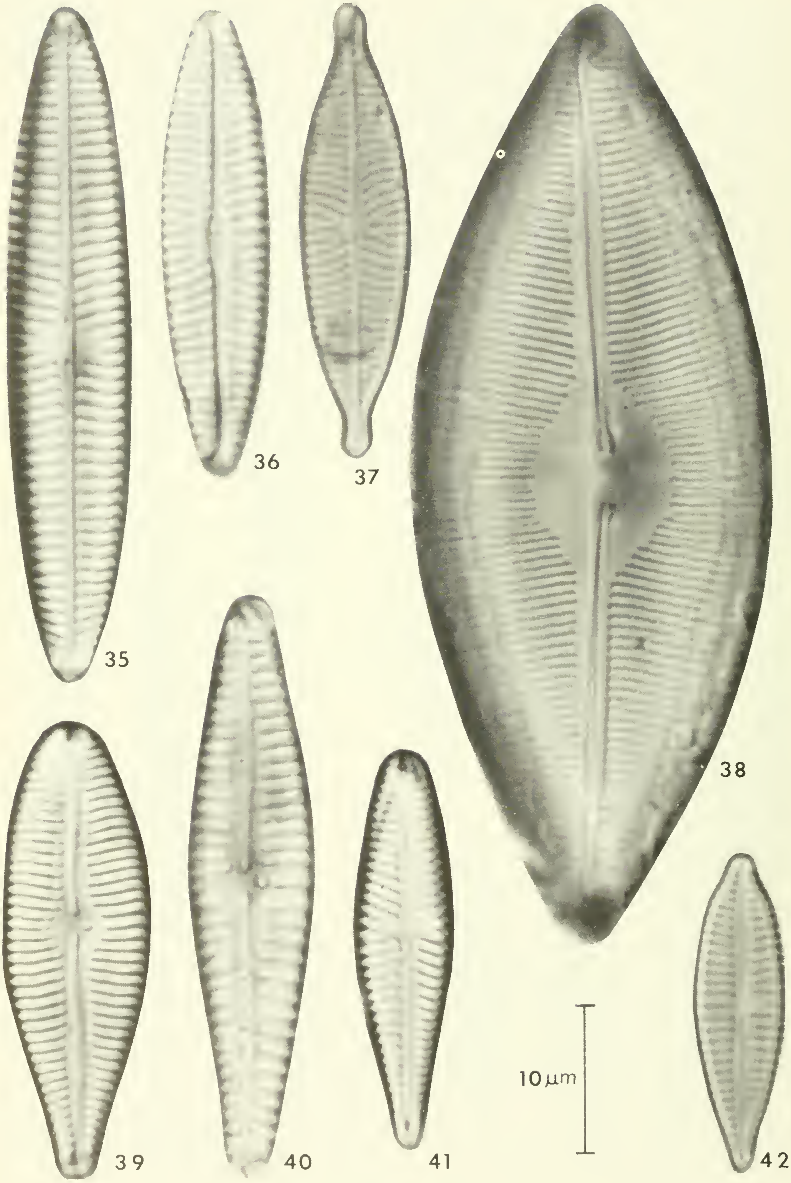
Nitzschia dissipata (Kuetz.) Grunow (Fig. 45). Cells 19–36 μm long by 4–5 μm wide; striae not resolvable; keel punctae 7–9 in 10 μm (Hustedt 1930:412). Collected frequently from all transects.

Nitzschia filiformis (W. Smith) Hustedt (Fig. 48). Cells 27–78 μm long by 5 μm wide; striae 32–34 in 10 μm; keel punctae 7–10 in 10 μm (Hustedt 1930:422). Frequent from most collecting localities.

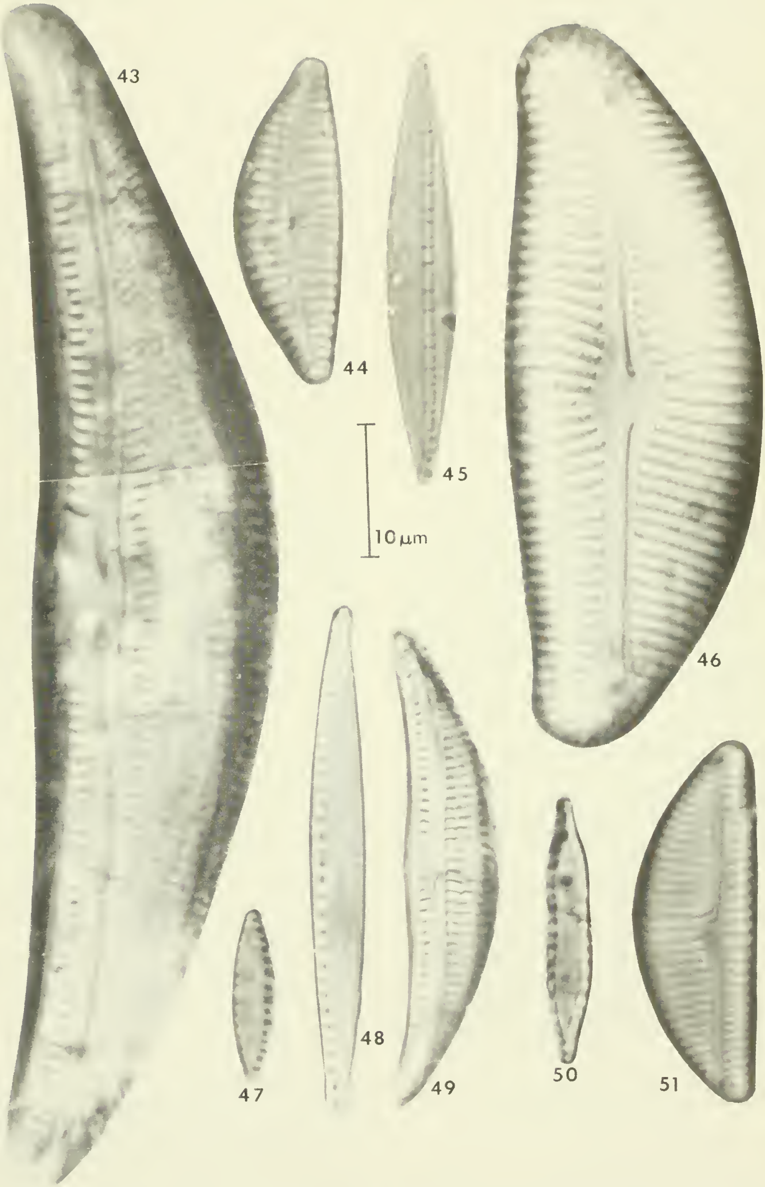
Nitzschia inconspicua Grunow (Fig. 47). Cells 6–15 μm long by 3–4 μm wide; striae 26–28 in 10 μm (Lange-Bertalot 1976: 265–266).

Nitzschia perminuta Grunow (Fig. 50). Cells 10–12 μm long by 3 μm wide; striae 24–35 in 10 μm; keel punctae 11–13 in 10 μm (Lange-Bertalot 1976:263). Collected frequently from all transects.

Nitzschia hantzschiana Rabenhorst. Cells 12–19 μm long by 2–3 μm wide; striae 20–24



Figs. 35–42: 35, *Navicula tripunctata*; 36, *Navicula graciloides*; 37, *Navicula salinarum* var. *intermedia*; 38, *Caloneis fenzlioides*; 39, *Gomphonema ventricosum*; 40, *Gomphonema intricatum*; 41, *Gomphonema olivaceum*; 42, *Gomphonema angustatum*. All figures are printed to the same scale.



Figs. 43–51: 43, *Amphora ovalis*; 44, *Cymbella affinis*; 45, *Nitzschia dissipata*; 46, *Cymbella prostrata*; 47, *Nitzschia inconspicua*; 48, *Nitzschia filiformis*; 49, *Amphora ovalis* var. *affinis*; 50, *Nitzschia perminuta*; 51, *Cymbella minuta* var. *silesiaca*. All figures are printed to the same scale.

TABLE 2. Algae standing crop in Utah Lake at selected sites along three permanent transects during the summer of 1974. The numbers represent total algal cells, colonies, and filaments per liter.

						Transect
	Goshen Bay					
Date	A	B	C	D	A	B
13 June 1974	1,007	1,702	2,417	1,778	10,528	619
20 June 1974	26,875	250	2,344	13,111	14,800	13,444
3 July 1974	24,917	48,500	39,250	78,667	17,506	30,042
8 July 1974	479,444	146,500	99,000	–	180,167	278,833
18 July 1974	629,167	216,250	260,500	203,333	922,222	710,416
27 July 1974	449,167	412,500	179,722	355,000	513,194	353,472
7 August 1974	59,815	30,000	20,375	122,917	1,111,667	280,000
15 August 1974	–	–	226,562	2,943,750	193,056	173,177

in 10 μm; keel punctae 9–11 in 10 μm (Hustedt 1930:415). Frequent from all collecting sites.

Division: Euglenophyta

ORDER: EUGLENALES

Euglena gracilis Klebs (Fig. 53). Plant unicellular and free swimming; cells metabolic, short fusiform to ovoid; chloroplasts many, discoid, distributed through cell; cells 20–22.5 μm in diameter, 37.5–50 μm long, may stretch to 75 μm long (Prescott 1962:393). Our most common *Euglena*. Abundant at mouth of Provo River, usually found with *E. ehrenbergii* and *E. oxyuris*.

Division: Pyrrophyta

ORDER: PERIDINIALES

Ceratium hirundinella (Muell.) Dujardin (Fig. 54). Plant unicellular and solitary; cells narrowly fusiform with one apical horn and 2–3 stouter and shorter basal horns; apical horn straight, truncately flattened at apex; cells 30–72 μm wide, 100–400 μm long (Prescott 1962:437). Although rare in early June, one of dominant plankters throughout remainder of summer. Often abundant enough to color water muddy-brown and to plug plankton nets.

Division: Cyanophyta

ORDER: CHROOCOCCALES

Microystis aeruginosa Kuetz. *em.* Elenkin (Fig. 55, 56). Colony spherical when young, becoming irregularly lobed and clathrate when mature; cells spherical and crowded within hyaline gelatinous matrix; cell contents blue green, highly granular, with conspicuous pseudovacuoles; cells 3–4 μm in diameter (Prescott 1962:456). Common to abundant in most plankton samples.

ORDER: NOSTOCALES

Anabaena spiroides var. *crassa* Lemmermann (Fig. 57). Trichomes spiral, solitary or entangled; cells spherical, pale blue green in color; cells 10–12 μm in diameter; heterocysts subspherical, 10 μm in diameter, 12 μm long; akinetes oblong, 20 μm in diameter, 25–30 μm long (Prescott 1962:518). Can be confused with *A. flos-aquae* but is less blue, less granular, more regularly coiled, and with larger cells. Abundant to common in most plankton samples. Occasionally forms fairly large blooms.

Aphanizomenon flos-aquae (Lemm.) Ralfs (Fig. 58). Trichomes parallel, united in bundles or flakes to form macroscopic aggregates; apices broadly rounded, not attenuate; cells 5–6 μm in diameter, 6–8 μm long, with numerous conspicuous pseudovacuoles; heterocysts oblong or cylindrical (Prescott 1962:528). Usually most abundant and conspicuous summer plankter in Utah Lake.

QUANTITATIVE SAMPLING

We have also performed quantitative sampling of the algal standing crop of Utah Lake. Our most complete data were collected during the 1974 collecting period. These data show that the standing crop of the lake was low during the spring and early summer (Table 2). At that time community diversity was high and the standing crop was divided

Table 2 continued.

and site							
Boat Harbor			Geneva				
C	D	E	A	B	C	D	E
1,424	1,448	625	647	719	1,971	743	5,590
–	2,055	2,311	5,750	17,500	5,939	144,667	–
35,625	27,778	51,250	293,499	19,850	41,917	16,958	5,944
263,833	174,333	104,667	857,016	954,384	199,653	120,500	75,333
917,361	811,111	402,083	–	119,666	906,249	468,750	568,750
351,389	242,014	203,819	277,083	457,291	–	–	–
114,583	280,417	74,167	605,556	701,042	300,694	6,333,333	102,292
284,722	591,667	450,000	15,833,332	6,944,444	22,750,000	77,816,656	2,133,333

between several taxa (Whiting et al. 1978). As the summer progressed community diversity decreased but standing crop increased. By late summer the standing crop was composed of essentially two species, *Aphanizomenon flos-aquae* and *Ceratium hirundinella.*

The high diversity as measured by the total number of species occurring in the lake coupled with the high late summer biomass leads us to conclude that Utah Lake represents a somewhat unique ecosystem. It is similar to certain other saline eutrophic systems in North America and Australia. Further studies on the algae of this system are presently underway.

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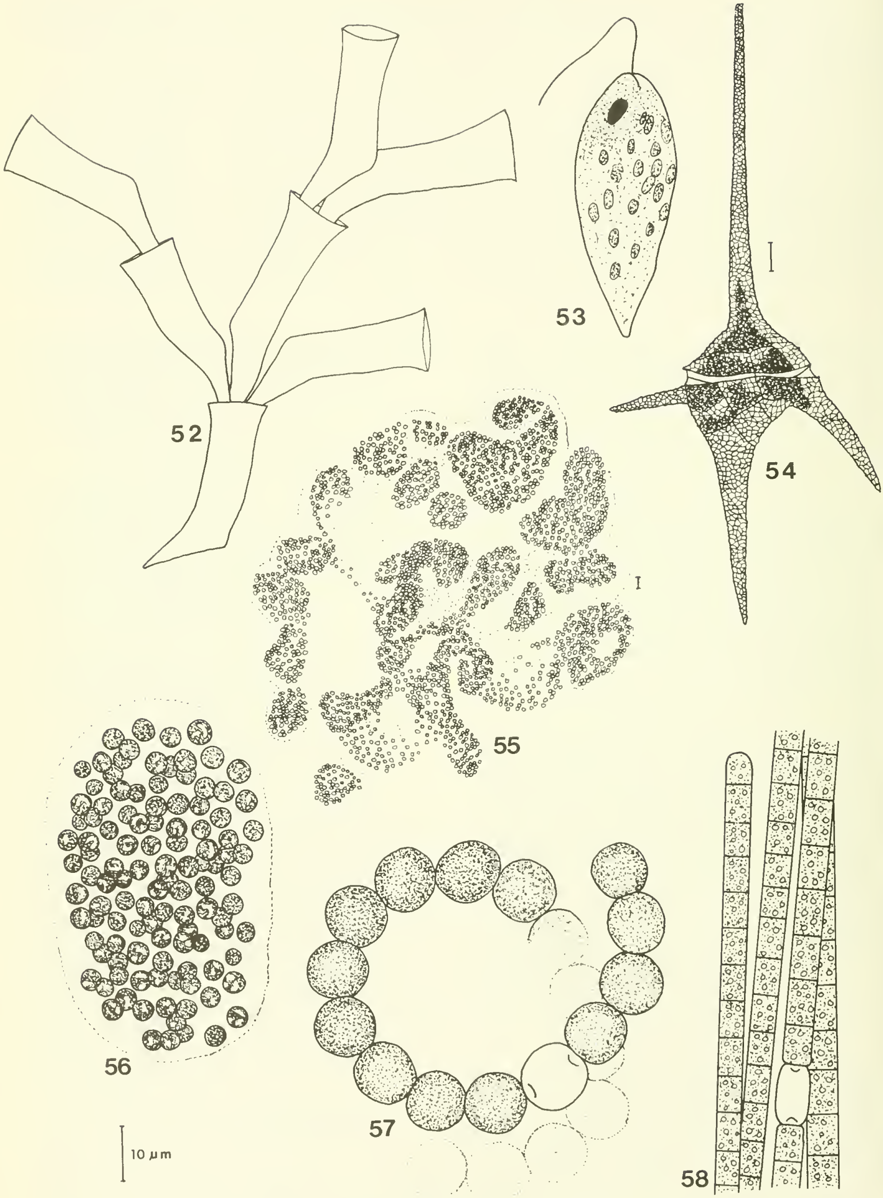

Figs. 52–58: 52, *Dinobryon divergens*; 53, *Euglena gracilis*; 54, *Ceratium hirundinella*; 55–56, *Microcystis aeruginosa*; 57, *Anabaena spiroides* var. *crassa*; 58, *Aphanizomenon flos-aquae*. All figures except 54 and 55 are drawn to the same scale. Scales provided represent 10 μm.

MACROINVERTEBRATE AND ZOOPLANKTON COMMUNITIES OF UTAH LAKE: A REVIEW OF THE LITERATURE

James R. Barnes[1] and Thomas W. Toole[1,2]

Abstract.— Early studies on the macroinvertebrates and zooplankton of Utah Lake were taxonomic in nature. Since the late 1960s, macroinvertebrate studies have concentrated on the Goshen Bay area of Utah Lake. The rocky shore macroinvertebrate community along the eastern shore of Goshen Bay is the most diverse and productive in Utah Lake (Toole 1973). The dominant organisms are the amphipod *Hyalella azteca* and the chironomid *Dicrotendipes fumidus*. Also present along the eastern shore is an extensive zone of the sponge *Meyenia fluviatilis* (Smith 1972). Two taxa, Chironomidae and Oligochaeta, dominate the silty-ooze community in the southern portion of Utah Lake (Barnes et al. 1974). The life histories and the microdistributional patterns of the two dominant chironomids found in the silt-ooze area of Goshen Bay, *Tanypus stellatus* and *Chironomus frommeri*, have been extensively studied by Shiozawa and Barnes 1975. The distribution and abundance of the zooplankton in Utah Lake has been studied for one summer (Hanson et al. 1974). Little is known about the dynamics of the zooplankton community in Utah Lake.

The first studies on the macroinvertebrate and zooplankton communities of Utah Lake were basically faunal lists of the protozoans, zooplankton, and Mollusca found in Utah Lake (Chamberlin and Jones 1929, Hunt 1940, Tanner 1930, 1931). The identifications of the species reported in the above papers have not been reexamined. Between 1940 and 1968 the macroinvertebrates received little, if any, attention. Brown (1968) conducted the first extensive study on the littoral macroinvertebrates of the Lincoln Beach area. Most studies since then have concentrated on the Goshen Bay region. This area, consisting of approximately one-third of the lake's total surface area, will be removed from the lake proper if the proposed Goshen Bay Dike (part of the Bureau of Reclamation's Central Utah Project) is built.

This paper reviews the literature of the macroinvertebrate and zooplankton communities of Utah Lake.

I. Littoral Zone

For a general discussion of the biological, chemical, and physical characteristics of lake littoral zones, see Wetzel (1975). Littoral zone studies in Utah Lake have concentrated on the rocky area along the eastern shore of Goshen Bay. In Utah Lake this rocky zone is the most extensive littoral area and supports a productive and diverse macroinvertebrate community (Toole 1974). In this area there are two main substrate types: compacted calcareous tufa (lacustrine) and rubble (Bissel 1942). Along the western shore of Goshen Bay, a similar rocky zone is found, although not as extensive. The eastern shoreline has numerous saline springs that are high in free carbon dioxide, bicarbonate alkalinity, and sulfate (Toole 1974).

Brown (1968) studied the fall and winter macroinvertebrate populations of Lincoln Beach. Samples were taken with a circular sampler at six stations along a 300 m stretch of rubble beach at a water depth of 0.5 m. The amphipod crustacean, *Hyalella azteca*, was the dominant macroinvertebrate in numbers, with the highest standing crop in September (mean number = 1,208/m^2). The next most dominant was the chironomid *Tanytarsus* sp. The highest density of this midge was in November (mean number = 320/m^2). Identification of this chironomid as *Tanytarsus* sp. is incorrect; it is probably *Dicrotendipes fumidus* (Toole 1974). The leech, *Helobdella stagnalis*, was next in abundance (150/m^2). Other organisms collected were a snail, *Physella utahensis*; a trichopte-

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ran, *Polycentropus* sp.; and a water mite, *Lebertia* sp.

Toole (1974), using concrete artificial substrate samplers, studied the standing crop (numbers and biomass) and the annual population trends of the dominant macroinvertebrates found in the rubble and lacustrine habitat along the eastern shore of Goshen Bay. The period of study was from March 1972 through May 1973. Throughout this study period the samplers were retrieved from an average water depth of 0.8 m. In the rubble area the amphipod *Hyallela azteca* and the chironomid *Dictrotendipes fumidus* were the dominant organisms on the samplers. Other organisms collected were *Polycentropus cinereus*, a trichopteran; *Helobdella stagnalis*, *Dina parva*, and *Erpobdella punctata*, leeches; *Ambrysus mormon*, a naucorid hemipteran; and the gastropod *Physella utahensis*. At the lacustrine sampling site the same species were collected, plus a planarian worm, *Dugesia dorotocephala*. Standing crop estimates were always higher from the rubble area than the lacustrine. In the rubble area the standing crop values depended on whether or not a set of samplers was within the influence of a saline spring. Those samplers within this influence always had a greater "algal mat" growing on them and the highest numbers of associated *Hyalella azteca*. The high concentration of free carbon dioxide and bicarbonate alkalinity in the spring water may be the reason for the higher algal standing crop. It is known that *H. azteca* feed on filamentous green and blue green algae and have the ability to select sediments that contain viable microflora (Cooper 1965, Hargrave 1970).

The number of *Hyalella azteca* reported by Toole from the rubble area is the highest found in the literature. The maximum estimate was 37,898/m² for August 1972. The highest biomass value (wet weight) was 66.5 gms/m² for April 1973. Assuming an 85 percent water content, the dry weight estimate would be 9.9 gms/m². These high standing crop estimates of *H. azteca* can probably be attributed to three factors: (1) an excellent substrate for epibenthic algae provided by the rubble and pieces of lacustrine substrate, (2) the eutrophic condition of Utah Lake and additional nutrients provided by saline springs, and (3) the combined effect of a shallow water depth over most of the littoral area and high water temperatures.

In March, April, and May, 1972, the *H. azteca* population consisted entirely of first- and second-year adults—the first-year adults making up 75 percent of the population. Immatures appeared in the population in June and dominated, in numbers, through October, thus making up 50–60 percent of the population. During this same time period, the numbers of second-year adults oscillated between 10–15 percent of the total population. In November, when the first year adults became dominant, there was a dramatic decrease in the percentage of immatures. The population overwintered as immatures and first- and second-year adults. In April 1973 (the first sample taken after the ice came off the lake) the population showed the same composition as found in November 1972. In May 1973 only first- and second-year adults were present in the population.

The chironomid *Dicrotendipes fumidus* overwinters as second, third, and fourth instar larvae, with the fourth being the most abundant. A major emergence occurred in March 1972 about three weeks after the ice broke up. Adults were found in the sampling area throughout the summer, which indicates a long emergence period. However, the emergences that took place throughout the summer were much smaller than the initial emergence. The highest larval density estimate was 21,421/m² in July 1972. At this time, the population consisted of second, third, and fourth instar larvae, with the third being dominant. The sieve used in this study restrained only the second, third, and fourth instar larvae. The high wet weight biomass estimate was 9.5 gms/m² or 1.4 gms/m² dry weight in September 1972. In that month third and fourth instar larvae dominated the population.

These high estimates are from artificial substrate samplers that had been located within the influence of spring water. The numbers of *Hyalella azteca* found on samplers located outside the influence of spring water exceeds other estimates found in the literature (Cooper 1965, Anderson and Hooper 1956, Buscemi 1961, Gerking 1962).

The littoral zone along the eastern shore of Goshen Bay supports the most productive and diverse macroinvertebrate community in Utah Lake (Toole 1974). When converted to dry weights (assuming a water content of 85 percent) and on the basis of only two species (*Hyalella azteca* and *Dicrotendipes fumidus*), the standing crop biomass values for this area ranks Utah Lake as one of the top 10 lakes found in the United States in terms of benthic standing crop (Cole and Underhill 1965). This comparison does not take into account the other species present in this area or the extensive zone of the sponge *Meyenia fluviatilis* (Smith 1972).

The trichopteran *Polycentropus cinereus* is rare in comparison to *Hyalella azteca* and *Dicrotendipes fumidus*. Emergence takes place in April along the Goshen Bay littoral area. The highest densities were 1,937/m², November 1972 (Toole 1974).

General population trends and emergence patterns of the dominant macroinvertebrates in the lacustrine area follow those found in the rubble area. The standing crop of the lacustrine area was smaller than reported for the rubble area. Brown's (1968) standing crop estimates of *Hyalella azteca* from the lacustrine area are difficult to compare with those obtained by Toole (1974) because Brown's sampling was limited to a water depth of 0.5 m or less. Toole's maximum estimate from the lacustrine area was 15,121/m², August 1972, which is 10 times greater than Brown's maximum estimate. Artificial substrate samplers retrieved from the lacustrine area always had less algae and more silt than samplers from the rubble area.

Tillman and Barnes (1973) studied the reproductive biology of the leech *Helobdella stagnalis* in the same rubble area studied by Toole (1974). The annual reproductive cycle of *Helobdella stagnalis* in Utah Lake is considerably different from the cycle found in Whiteknights Lake, Reading, Berkshire, England (Mann 1957). Mann reported that overwintering adult leeches produced a brood of young in May and then died in June. Over 50 percent of the new brood matured and reproduced in July and August and died after reproduction. The next year's overwintering leeches were composed of June leeches that did not mature and July-to-August leeches produced by the mature June brood leeches. Tillman and Barnes found in Utah Lake that overwintering adult leeches have a first brood of young in May that release from the adults in mid-June. Then the same adults bear a second brood of young in late June and early July. The adults disappear from the population after the second brood of young. Very few first and second brood leeches mature and reproduce that same summer. The leeches from the first and second brood then become the next overwintering population.

II. Clay-Silt Area

For a description of the substratum composition, see Bingham (1974). Barnes et al. (1974) sampled the clay-silt area of the southern part of Utah Lake monthly from September 1971 to September 1972, except when the lake was iced over. Two transects (1 and 2) were located in the area of Goshen Bay to be diked off and the other two (3 and 4) were located in front of the proposed dike (the area to be retained as part of the lake). Only two dominant taxa were found: Chironomidae and Oligochaeta.

Oligochaetes collected in this study were not classified. Preliminary examinations indicate that there are three dominant oligochaete species. During the period of study, the mean number of oligochaetes collected ranged from 8643/m² to 26,192/m². In general the oligochaetes showed a decrease in numbers during the spring and then an increase during late summer and early fall.

There are at least three species of chironomids present in the silty clay area: *Chironomus frommeri, Tanypus stellatus,* and *Procladius freemani*. They were not separated to species when sorted to taxa and only total numbers were reported. The mean number of chironomids ranged from 237/m² to 7167/m². Like the oligochaetes, the chironomids showed a decrease in numbers during spring and then an increase during late summer and fall. Because of the screen size used in sieving, the numbers of chironomids are represented by only second, third, and fourth instars of the larger species and third and fourth instars of the smaller species.

Analysis of variance (ANOVAR) was used to compare the mean number of chironomids and oligochaetes in the following contrasts:

Transects 1 and 2 versus 3 and 4, transect 1 versus 2, and transect 3 versus 4. At the 0.05 level there was a significant difference between the oligochaete means of transects 1,2 (area to remain in the lake) and transects 3,4 (area to be diked off). There were no significant differences between the oligochaete means in 1 versus 2 and 3 versus 4. The chironomid means showed no significant differences in any contrasts at the 0.05 level.

The numbers of oligochaetes per square meter in Utah Lake are consistent with numbers reported from other eutrophic waters. In Toronto Harbor, Lake Ontario, which is grossly polluted, the oligochaete population averaged 96,000/m² (Brinkhurst 1972) with one worker reporting densities of well over a million/m² (Aston 1973). The low number of oligochaete species present in the clay-silt of Utah Lake is consistent with other shallow lakes that also show little diversity in benthic habitat. Heuschele (1969) studied the benthic community of a shallow floodplain lake and found only three species of oligochaetes present. Utah Lake, like the flood plain lake, has little to no rooted aquatic vegetation present and a majority of the lake substratum is quite uniform with respect to chemical factors, temperature, depth, and light. Greater numbers of oligochaete species are found in deeper lakes with more diverse habitats. Thirty-three species have been reported from Lake Maggiore (Brinkhurst 1963) and 22 from Esrom Lake (Berg 1938). In comparison with deeper, oligotrophic lakes (Thut 1969), Utah Lake has a low number of chironomid species. The density of chironomids found in the Goshen Bay area is consistent with that found in shallow lakes (Heuschele 1969).

Shiozawa and Barnes (1977) studied the microdistributional patterns and life histories of larval *Tanypus stellatus* and *Chironomus frommeri* in Goshen Bay from July 1973 to August 1974. Vertical distribution data showed that over 90 percent of the larvae were located in the top 7.5 cm of the substratum. Depth of penetration into the substratum increased with the later instars. The *C. frommeri* larvae penetratd deeper than those of *T. stellatus*. Biomass was distributed bimodally. The mode at the 0–2.5 cm depth was due to high numbers of early instar larvae. The second mode, at the 17.5–20.0 cm depth, was due to the presence of fourth instar *C. frommeri* larvae. The *T. stellatus* showed a contagious distribution in the early instars with a trend toward randomization within the later instar stages. The *C. frommeri* larvae rarely showed contagious distributions. This was likely related to their low abundance in the samples, making detection of a contagious distribution difficult.

Larvae of *T. stellatus* overwintered in the first and second instar. This overwintering generation emerged in early July and gave rise to a second summer generation emerging in August. *Chironomus frommeri* overwinter mainly as third and fourth instar larvae. Emergence occurred throughout the summer, although two strong emergence pulses were seen; one occurred in May and the second in July–August.

III. Zooplankton

Hanson et al. (1974) sampled the zooplankton in Utah Lake during a three-month period from June to August 1974. Transects were chosen to represent three subenvironments within the lake. The northern or Geneva transect ran west from the settling pond spillway of United States Steel's Geneva Works. Five sites were sampled. The middle or Boat Harbor transect also had five stations running west from a point just south of the mouth of the Provo River and north of Provo Bay. The southern or Goshen Bay transect, being shortest with only four sampling sites, ran west from Ludlow's sheep barns near Lincoln Beach. Samples were collected every nine days between 4 June and 15 August 1974.

A complete list of the zooplankton identified in this study is given below (those marked by an asterisk have not previously been reported):

Copepoda
- *Diaptomus spp.* (two species)
- *Cyclops spp.* (two species)

Cladocera
- *Daphnia retrocurva*
- *Pseudosida bidentata*
- *Leptodora kindtii*
- **Bosmina longirostris*
- *Chydorus sphaericus*
- *Ceriodaphnia sp.*

Rotifera
Keratella cochlearis
Keratella quadrata f valga
Keratella quadrata f frenzeli
°*Brachionus caudatus*
Brachionus calcyflorus
Brachionus budapestensis
Filinia terminalis
°*Polyarthra sp.* (*minor* or *remata*)
°*Synchaeta sp.*
°*Notommata sp.*
°*Asplanchna sp.*
°*Colurella sp.*
°*Cephalodella sp.*

Most zooplankton species were present at all stations, though their frequencies varied rather widely. Areas influenced by the inflow from the Provo River showed more diversity, less dominance by few species, and larger standing crops. Using the variance to mean ratio (Elliott 1971), zooplankton distribution in total numbers was determined to be aggregated. Populations in large clumps make it very difficult to determine accurate standing crop estimates. For instance, two samples taken on the Boat Harbor transect at Station A on two consecutive days, 21 June, and 22 June, illustrate this. The 21 June sample contained 398,000 zooplankton/m^3; the sample collected the following day contained only 50,000 zooplankton/m^3. Relative densities of individual species in the two samples were also very different.

Some zooplankton population trends were observed. In the northern two transects, the total zooplankton numbers peaked in late June and early July, then dropped off in August. No pattern was as obvious in Goshen Bay, although highest numbers were observed in early August. Trends in some populations are reported. In early samples the calanoid copepods dominated, with their dominance decreasing steadily throughout the summer; by August *Daphnia retrocurva* and *Pseudosida bidentata* were found in slightly higher numbers than the calanoids. *Pseudosida* populations were stable, although *Daphnia* populations seemed to show a slight inverse proportionality to calanoid populations. This tendency was more evident in Goshen Bay than in the other parts of the lake. A more obvious trend was the increase through the summer in numbers of predatory cyclopoid copepods and *Leptodora kindtii*. No correlations between phytoplankton and zooplankton populations were made.

Acknowledgments

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FISHES OF UTAH LAKE

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Abstract.— There has been a drastic change in fish populations inhabiting Utah Lake during the last 100 years. When the pioneers first entered Utah Valley they found a well-established cutthroat trout population in Utah Lake and in the tributaries flowing into the lake. After intensive agricultural and industrial development this salmonid disappeared, and carp, white bass, and black bullhead are the common species today. The known history of the Utah Lake fisheries is summarized. Through proper management it is possible to establish a sport fishery of the common fish species currently in the Lake, including walleye, channel catfish, and largemouth bass. The ichthyofauna of Utah Lake may be an underrated natural resource. Today, no native sport fishery exists in Utah Lake, although sportsmen are harvesting introduced species. Utah Lake has a dynamic fishery that must be continually monitored and managed if it is remain productive.

The ichthyofauna of Utah Lake has experienced drastic changes since the white man entered Utah Valley to colonize the agricultural lands. This lake, which once had a wealth of trout, suckers, and minnows, now contains carp, white bass, and black bullheads. Proper management of the sport fish and commercially important fish is of primary concern to district fishery biologists.

Utah Lake is a warm, shallow, eutrophic body of water in Utah County, Utah, which may be the most underrated natural resource for fishes in the state. The fishes currently in Utah Lake could be an important source of needed protein for human consumption in the near future.

The native fishes once associated with the lake are the cutthroat trout, mountain whitefish, Utah chub, leatherside chub, least chub, longnose dace, Utah sucker, webug sucker, June sucker, mountain sucker, mottled sculpin (Bonneville), and Utah Lake sculpin (Tables 1,3). Included are 4 families, 9 genera, 12 species, and 2 subspecies. There has been a drastic change in the ichthyofauna since man settled Utah valley.

Accounts of the early history of Utah indicate that Utah Lake was a productive,

Table 1. Utah Lake fish species in order of decreasing abundance as shown by gill net catches in 1958 and 1970.

Order	1958	1970
1	Carp	White bass
2	Utah chub	Black bullhead
3	Channel catfish	Carp
4	Perch	Walleye
5	Utah sucker	Channel catfish
6	Black bullhead	Utah sucker
7	Walleye	
8	White bass	

Table 2. Pesticides and mercury in fish taken from Utah Lake in ppm (wet muscle tissue measure) (Smith 1973).

	Mean	Range
Mercury		
Carp and bullhead	0.152	0.030–0.470
White bass[1]	0.050	
Dieldrin		
Carp	0.012	0.000–0.023
Bullhead	0.007	0.004–0.010
White bass[1]	0.011	
p,p'-DDT		
Carp	0.011	0.000–0.036
Bullhead	0.012	0.003–0.020
White bass[1]	0.021	
p,p'DDE		
Carp	0.020	0.000–0.056
Bullhead	0.007	0.000–0.013
White bass[1]	0.056	
PCB's		
Carp	0.115	0.000–0.200
Bullhead	0.100	0.100–0.100
White bass[1]	0.180	

[1]Analysis by WARF Research Institute, Madison, Wisconsin in November 1970.

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beautiful lake teeming with native cutthroat trout weighing 15 to 16 pounds. Since the Mormon settlers entered Utah Valley in the early 1850s there has been a steady decline in the quality of fisheries. The once abundant native cutthroat trout is now extinct and the large number of suckers that once existed are on the decline. Introduced species are now the most common fish in the lake (Tables 1 and 4). The major causes of the decline of the fisheries in Utah Lake include extensive commercial fisheries, water manipulation, agricultural practices, and pollution. Diversion and blocking of the feeder streams to Utah Lake reduced access to spawning areas used by the cutthroat trout and the suckers. Fluctuations in the water level, and water quality, poor agricultural practices, and increased sewage effluent reduced the water quality for the feeder streams and in Utah Lake. The introduction of exotic fish species caused extensive competition with the native fish stock. Carp became one of the most abundant fish, and their activities contribute greatly to the high turbidity of the lake water. The carp are, however, utilized to some extent by a lo-

TABLE 3. Current status of native fishes of Utah Lake.

Fish	Status 1977	Comments
Salmonidae		
Salmo clarki (Bonneville cutthroat trout)	Lake form extinct, river form hybridized	Common to west side Wasatch Mountains. Probably two races: a large lake dweller and a river dweller. Grew to 18 pounds in the lake.
Prosopium williamsoni (Mountain whitefish)	Rare in lower Provo River	Probably entered river deltas in the lake. Was common in early commercial fishery; called mountain herring.
Cyprinidae		
Gila atraria (Utah chub)	Very rare	Common in lake until early 1960s. Probably eliminated by introduced walleyes and white bass.
Iotichthys phlegethontis (Least chub)	Extinct	Few still found in Kamas Valley-Provo River and other areas in Utah. Habitat loss in lake.
Gila copei (Leatherside chub)	Extinct	Some in Kamas Valley-Provo River and other areas in Utah.
Rhinichthyes cataractae (Longnose dace)	Rare	Few in Current Creek south tributary, Utah Lake. Common in other streams in Utah.
Catostomidae		
Catostomus ardens (Utah sucker)	Rare-common	Once very common in Utah Lake and inlet streams. Filled rivers with spawners in spring.
Catostomus fecundus (Webug sucker)	Rare	May be hybrid between June and Utah sucker. Widely distributed in lake.
Chasmistes liorus (June sucker)	Rare-extinct	Once very abundant, now near extinction. Probable plankton feeder; terminal mouth.
Catostomus playtrhynchus (Mountain sucker)	Few, status unknown	Inlet streams of Utah Lake, never ventured far into lake.
Cottidae		
Cottus bairdi semiscaber (Bonneville mottled sculpin)	Many	Provo River and other inlet streams.
Cottus echinatus (Utah Lake sculpin)	Rare, none collected since 1930s	Small spring inlet streams originating in Utah Valley. Common in Bonneville sediments where fish fossils found.

TABLE 4. Fish introductions in Utah Lake and its tributaries, 1880–1974.

Family, accepted common name	Date, number introduced	location	Fate
Clupeidae			
American shad	1887 (2,000,000 fry), 1888 (2,000,000 fry)	Utah Lake Utah Lake	1889; 1¾ lb shad. For sale—soon died out.
Salmonidae			
Silver salmon	1927 (325,000 fry)	Utah Lake	Died out.
Rainbow trout	1894, 1900	Provo River	Probably sustained in Provo River
Brown trout	Prior 1900, planted regularly by 1910.	Provo River, most inlet streams	Became self-sustaining in Provo River.
Lake trout	1894 (100,000 fry), 1900 (250,000 fry) 1900 (50,000 fry)	Unknown Spring Creek Provo River near Heber, Utah	1905 evaluation, no favorable results
Brook trout	1894 (500 12" long) 1895 (1,000 adults) 1903–to present—occasional stocking	 Most inlet streams Up high in inlet streams and lakes	1905, doing well in Provo River; subsequently died out. Mostly put and take; some reproductions.
Lake whitefish	1895 (2,000,000 fry) 1919 (2,000,000 fry) 1921 (100,000 fry)	Utah Lake Utah Lake Utah Lake	No populations established.
Grayling	1899 (30,000 fry)	Inlet streams, Utah Lake	No populations established.
Anguilidae			
American eel	1872 1887 (80 up to 18")	Pond on Jordan River Jordan River	1874, 1½ lb take near mouth of Provo River. 1894, few taken up to 30" from Utah Lake; never became established.
Cyprinidae			
Gold fish	1881 (130 adults) (47 adults), occasional small releases through 1974	Ponds near Jordan River Utah Lake	Few taken by commercial fishermen each year.
Carp	1882 (200 young) 1883 (?) 1886–1903 several thousand	Ponds near Jordan River Jordan River Utah Lake	Successful; population rapidly expanded until very abundant in Utah Lake and lower inlet streams.
Golden shiner	1969 (100,000 to 200,000)	Various locations around Utah Lake	May have become established.
Fathead minnow	1969 (100,000 to 200,000)	Various locations around Utah Lake.	Occasional in littoral zone.
Bullhead minnow	1969 (?)	Various locations	Occasional in small inlet streams.

Table 4 continued.

Family, accepted common name	Date, number introduced	location	Fate
Ictaluridae			
Channel catfish	1888	Utah Lake	Has become common in Utah Lake. Reduced in recent years.
	1911	Utah Lake	
	1919	Utah Lake	
	1920	Utah Lake	
Black bullhead	1871	Jordan River	1900, became common in Utah Lake fishery. Very abundant, 1974.
	1873	Jordan River	
	1893 (100 6-15")		
Percidae			
Yellow perch	1890	Utah Lake	1894, present in commercial catches
	1891 (636)	Utah Lake	
	1923	Utah Lake	
	1931	Utah Lake	
	1932	Utah Lake	1934, drought killed many. Occasional catch, 1974.
Walleye	1952 (600,000)	Utah Lake	
	1954 (300,000)	Utah Lake	First spawning runs. Provo River, 1955 or 1956
	1956 (900,000)	Utah Lake	
	1968–1973 (19,907,594)	Lower Provo River Benjamin slough	
Centarchidae			
Smallmouth bass	1912 (160)	Spring Creek	Not established.
	1914 (600)	Spring Lake	Fishery for short time then died out.
Largemouth bass	1890 (mixed sizes)	Utah Lake	1893, bass season opened.
	1891 (1,700 fry)	Utah Lake	1895, 2000 spawners taken for planting elsewhere.
	1894 (100 adults)	Utah Lake	
	1902–1913	Powell slough used as natural hatchery	1902, population down.
	1912 (5,000,000 fry hatched in Powell slough)		1901, commercial seining outlawed; became common along shore.
Green sunfish	1890 (mixed)		Established in stream inlets.
	1930–1949	Various inlet streams and Jordan River	
Bluegill	1890 (mixed)	Various inlet streams and Jordan River	Occasional along shore.
Black crappie	1890	Utah Lake	Unknown but rarely if at all taken.
	1895 (85 adults)		
	1931, 1932, 1933—several thousand young	Mouth of Provo River	1934, drought killed most.
Serranidae			
White bass	1956 (209 mixed)	Utah Lake	Very abundant.

cal commercial fisherman and could become a source of human food in the future. White bass, another introduced species, is also very abundant in the lake. Table 5 lists the current species in Utah Lake and their relative abundance. (The text contains a description of each of the common species currently in Utah Lake.)

TABLE 5. Checklist of the fish species currently found in and near Utah Lake, Utah County, Utah, with information concerning their relative abundance.

Species	Abundance in 1977
Brown trout (*Salmo trutta*)	rare (inlet streams)
Cutthroat trout (*Salmo clarki*)	rare (extinct in Utah Lake)
Rainbow trout (*Salmo gairdneri*	rare (inlet streams)
Carp (*Cyprinius carpio*)	very common
Utah chub (*Gila atraria*)	very rare
Fathead minnow (*Pimephales promelas*)	rare
Golden shiner (*Notemigonus cryspleucas*)	rare
Redside shiner (*Richardsonius balteatus*)	rare
Utah sucker (*Catostomus ardens*)	common-rare
June sucker (*Chasmistes liorus*)	rare-extinct
Webug sucker (*Catostomus fecundus*)	rare
Mountain sucker (*Catostomus platyrhnchus*)	very rare
Channel catfish (*Ictalurus punctatus*)	common
Black bullhead (*Ictalurus melas*)	very common
Mosquitofish (*Gambusia affinis*)	common
White bass (*Morone chrysops*)	very common
Largemouth bass (*Micropterus salmoides*)	common
Green sunfish (*Lepomis cyanellus*)	common
Bluegill (*Lepomis macrochirus*)	common
Yellow perch (*Perca flavescens*)	rare
Walleye (*Stizostedion vitreum*)	common
Mottled sculpin (*Cottus bairdi*)	rare

To date 25 species of fish have been introduced into Utah Lake (Popov 1949). Thirteen of these introductions were successful and 11 failed (Table 4). The carp, white bass, black bullhead, channel catfish, and walleye have been the most successful. The status of the golden shiner and the fathead minnow is unknown, but it is hoped that these two minnow species will provide a forage fish for the larger piscivorous fish such as the walleye and largemouth bass.

Today, no native sport fishery exists in Utah Lake. The fish species utilized by the sportsmen are all introduced. The most widely fished-for species are the channel catfish, black bullhead, walleye, and white bass.

The walleye fishery appears to be stabilized with annual stockings of sac-fry to supplement the natural spawn. There is substantial fishing pressure for this species, particularly in the early spring during their spawning period. The number of walleye collected in nets and caught by fishermen increased in 1970 over that in 1958, a fact that shows the beginning of an established walleye fishery in the lake.

A brief annotated history of the fisheries of Uah Lake prior to 1849 on to 1974 is found in Table 7.

Origin of Native Fish Species

The native fishes of Utah Lake are most nearly related to those of the Columbia River Drainage. The Columbia River element probably reached Utah Lake by means of a river connection established during the late Pliocene-Pliestocene, when the continued uplift of the Sierra Nevada, glaciation, and vulcanism interacted to change the direction of Great Basin river outflow from a Mississippi-Atlantic Ocean connection to a Columbia River-Pacific Ocean connection (Hubbs and Miller 1948). Demographic evidence of this relationship is found in the similar genera of the families in Pliocene-Pliestocene times and recently (see Table 6).

The reasons why some families and genera that were in Lake Bonneville are not now represented in Utah Lake or even in Utah, are not known. However, if Lake Bonneville dried up between 8000 and 5000 BC, leaving only springs and streams (Bissell 1968), then the more lake-dependent species could have been eliminated.

This idea is supported by the fact that all native species of Utah Lake fish (1880 AD) had both lake and river spawning forms and depended heavily upon river-produced young for recruitment. In addition, *Prosopium spilonotus*, a lake species, was common in Lake Bonneville but is now restricted to Bear Lake (Stokes et al. 1964).

TABLE 6. Comparison of fish faunas (families, genera) of Lake Idaho, Lake Bonneville, and Utah Lake.

Lake Idaho (Late Pliocene)	Lake Bonneville (Late Pliestocene)	Utah Lake drainage 1880 A.D.)
Salmonidae	Salmonidae	Salmonidae
Salmo	*Salmo*	*Salmo*
Prosopium	*Prosopium* (2 spp)	*Prosopium*
Cyprinidae	Cyprinidae	Cyprinidae
Ptychocheilus	*Gila*	*Gila* (2 spp)
Arcocheilus		*Iotichthys*
Diastichus (2 spp)	*Rhinichthyes*	
Mylocyprinus		
Mylopharodon (2 spp)		
Sigmopharyngodon		
Catostomidae	Catostomidae	Catostomidae
Catostomus (5 spp)	*Catostomus*	*Catostomus* (2 spp)
Chasmistes		*Chasmistes*
Deltistes (2 spp)		
Ictaluridae		
Ictaluris		
Centrarchidae		
Archoplites		
Cottidae	Cottidae	Cottidae
Cottus	*Cottus* (2 spp)	*Cottus* (2 spp)

Fisheries, American Indian Period

Although written records are few, there is evidence that fish from Utah Lake and its tributaries were utilized by various American Indian cultures that inhabited Utah Valley and adjoining areas. In 1776, Fathers Dominquez and Velez de Escalante described Utah Lake as teeming with several kinds of edible fish. That the natives dried the fish for later consumption is evidenced by the supply of dried fish the Spanish took with them when they left Utah Valley (Auerbach 1943).

Early trappers and explorers found similar utilization of the fisheries (Bagley 1964, Fremont 1845, Stansbury 1852), and they caught many of their fish during the spawning season in late spring and early summer by wading into a riffle and manually throwing them on to the bank (Pratt 1849). Remains found in archeological "digs" around Utah Lake have found fish use from 800 to 1300 AD by the Sevier-Fremont culture (Green 1961, Wheeler 1968). Early Mormon settlers were also exposed to the Utah Lake fishery by the native Americans whom they replaced in Utah Valley.

Founding of the Commercial Fishery—1880

The first Mormon pioneers stopped at Fort Bridger, Wyoming, where William Clayton recorded a discussion between Jim Bridger and Brigham Young (Clayton 1921). Bridger felt that the region around Utah Lake was the best country in the vicinity of the great Salt Lake, because there were timber near the streams and an abundance of fish in the streams, south from Utah Lake.

The summer arrival of the Mormons (24 July 1847) into the Salt Lake Valley, the impending winter, the need to build shelter and prepare ground for crops, and the knowledge of those waiting to come left little time to explore. However, in December 1847, Parley P. Pratt and party traveled to Utah Lake with a boat and fish net. They sailed the western side of the lake and caught a few mountain trout and other fish (Pratt 1888). Carter (1969) felt that their lack of success was because the trout went to deeper waters in the winter. However, Pratt's party fished the west side of Utah Lake, which was never known for its trout populations.

TABLE 7. Brief annotated history of the fisheries of Utah Lake, 1849–1974.

Date°	Activity	Possible causes
Prior to 1849	American Indians caught and used fish from Utah Lake for at least 500 years (Auerbach 1943, Fremont 1845, Green 1961).	
1849	Spawning fish (trout, suckers, and mullet) in lower Provo River, dried or salted in barrels. Beginning of commercial fishery in Provo River and Utah Lake (Green 1961, Huntington 1847).	Provided sustenance to Provo settlers who had to clear ground.
1850–1852	Spawning fish in rivers and streams still caught. Nets and traps more common, advent of boats and lake year-round fishing. Fishermen from Provo and other settlements. Lower Provo River Fishery predominates (Huff 1847).	Settlement of American Fork, Lehi, Pleasant Grove, Springville, Spanish Fork (Palmyra), Payson, and Alpine—all consumed fish (Gardner, 1913, Hons 1950, Johnson 1900, Carter 1969).
1850–1860°	Rapid increase in commercial fishing with year-round harvest; long seines introduced. Selling of fish common in Utah Valley and Salt Lake Valley. Permanent fish traps allowed along millrace in lake fishing streams. Gradual decline in American Indian fishing. Higher prices obtained in winter than summer. State, county, and local governments begins some regulation of fishing. Provo City regulated the Provo River, while Utah County regulated the fisheries of Utah Lake and other streams (Spanish Fork, Jordan River, Payson Creek, and Provo Bay streams) (Bean 1852, Utah Legislative Assembly 1855, Carter 1969).	Mormon population grew from 6,000 in 1849 to 40,000 in 1860 (Arrington 1966). Drought and grasshopper plague, 1855–56 (Jarvis 1962, Madsen 1910). Severe winter weather and Indian depredations reduced cattle. Coming of Johnston's Army, 1857–58, added burden on resources as Salt Lake Valley settlers fled south (Arrington 1966).
1856	Peter Madsen begins long-term fishery at the mouth of Provo River and south (Carter 1969).	
1860–1870	Decline in number of commercial fishing groups; consolidation of fishing areas. Peter Madsen picks up other areas for expanded fishery (J. Procd. Provo City Council 1866, 1872).	
	Some decline in fishery noted. Manufacture of fish oil for leather and machinery began (Burton 1860, Carter 1959).	All inlet streams of Utah Lake appropriated for irrigation by 1874. Loss of recruitment as age 0 fish turned out on the land (Israelson 1938).
1860–1974°	Spawning fish, their eggs, and young destroyed by fluctuating water levels of inflow streams into Utah Lake; reduced fish populations (Winger 1972).	Regulation of inflow streams primarily for irrigation.
1862	Territorial legislature took over regulation of Jordan River Fishery and outlawed fish traps (Utah Legislative Assembly 1866).	Overfishing during spawning season.
	Peddlers or middle men developed, buying the fishermen's catch and then selling them in Utah and Salt Lake Counties (Carter 1959).	
	Set line fishery with many hooks becomes popular for trouting. Gill netting was practiced but declared illegal by the Utah County Court (J. Procd. Utah County Court 1857, 1894).	

Table 7 continued.

Date*	Activity	Possible causes
1863	Jens Michelson begins long-term fishery, mouth of Spanish Fork River (Carter 1959).	Serves south Utah County and market for fish oil.
1870	The fishing decline was noticed and a special committee was appointed in 1870 at the general conference of the LDS Church to develop fish culture (Popov 1949).	Return water from irrigated fields and cities warmer and higher in salt and silt load.
1870–1974	Change of inflowing waters quality; from cold, clear snowmelt to turbid warmer, more nutrient-rich waters (White et al. 1969).	Diversion of surface waters into irrigation, urban, and industrial use, then returned.
1872	Yarrow and Cope visited and felt the trout fishery had declined by about ⅓. Several court cases on mesh size of siene and unlicensed fishermen. Fish traps must have free passage when not in use. The lake cutthroat esteemed above all other fish for flavor. Beginning of sports fishing in greater numbers (Cope and Yarn 1875).	First dam built across Jordan River, beginning of lake level manipulations. Beginning of riverbed manipulations. Beaver dams destroyed, channelization, stream bank denuding becomes severe (*Salt Lake Tribune* 31 July 1932). More leisure time, larger population of younger people.
1875	Continued decline in catch, still a ready market. Utah Lake trout shipped to western (California) and eastern (Denver and Chicago) markets by railroad (J. Procd. Utah County Court 1894).	Higher prices in out-of-state markets. Completion of Central Utah Railroad branch.
1876	Territorial legislature bans seining and poisons or explosives, and requires a fish passageway in all dams. Setlines reduced to 3 hooks per line (Utah Legislative Assembly 1876).	Concern over decrease territorywide on fish, particularly Utah Lake trout.
1878	First Utah County fish and game commissioner appointed (Utah Archives #25, 1940:279–80).	
1880	Entrances of all irrigation canals should be screened (Utah Legislative Assembly 1880).	General knowledge that irrigation practices were destroying many fish.
1880	Visit by David Starr Jordan, who described Utah Lake as universe's greatest sucker pond (Jordan and Gilbert 1881, *Salt Lake Tribune* 1923).	Changing fish population, suckers gaining ascendency.
1882	Lawful to fish with seine 200 yds long by 12 ft wide, mesh 2 inch center and 1½ inch in wings (Utah Legislative Assembly 1882).	Complaint by Madsen and others.
1884	Mesh size reduced 1½ in for 50 ft center. Compromise point for Utah Lake level reached (Utah Legislative Assembly 1884).	Result of years of haggling between Salt Lake and Utah Counties over lake level.
1886	Screen law for irrigation ditches repealed because a nuisance to clean screens. Carp introduced into Utah Lake (Utah Legislative Assembly 1886).	Farmers win their view in territorial legislature.
1888	Season established from 1 October to 1 June to legally seine or hook and line fish for trout. Set line fishing prohibited. However, it continued through 1930s on commercial scale. Still (1974) practiced by some sports fishermen (Utah Legislative Assembly 1888).	Concern over sharp decline in catch of trout. Was best way to catch large trout, bass, and catfish without sorting course fish.

Table 7 continued.

Date°	Activity	Possible causes
1890	Territorial game warden appointed. Large mouth bass introduced into Utah Lake (Utah Legislative Assembly 1890).	No one enforced laws before.
1890–1894	Black bullheads, channel catfish introduced into Utah Lake (Popov 1949).	Desire to improve fishing in Utah Lake.
1893	C. F. Decker and Co. begins buying Utah Lake fish from Madsens. Sell from ice wagons to Salt Lake City markets (Scott 1951).	Economic demand, public desire shifts from dried and salted to fresh fish.
1894°	Carp and large mouth bass common in seine hauls. People accept them and they become a regular part of commercial fishery. Still many suckers and chubs (Popov 1949).	Introduced species become acclimated and rapidly expand in numbers.
1894	Most trout shipped out of territory. Suit brought in Utah County court to halt practice (Utah County Court Journal 1894:186).	Higher prices, desire for cash or out-of-territory credit.
1895	Large mouth bass become very common in Utah Lake; catch is 5:1, bass to trout, while suckers, chubs, and other common fish (carp?) are caught 18:1 to bass and trout (*Deseret Evening News* Jan. 16, 1895).	Decline of trout, large numbers of forage fish to feed bass.
1897	Only carp, chubs, mullets, and suckers can legally be taken by seine; however trout and large mouth bass can still be taken by hook and line then sold through 1904. Game wardens must accompany seiners. Legal net not to exceed 200 yds (Scott 1951).	Cutthroat population very reduced. Increased hook and line fishery for bass and trout.
1897	Mills, factories, power plants, and manufacturing concerns required to install fish screens in intake canals (Utah Legislative Assembly 1897:94–95).	Reduce unnecessary destruction of fish (was not enforced strongly).
1897	Unlawful to seine within half mile of inflowing river into Utah Lake. Unlawful seines destroyed. Game warden had to go on every seining trip (Utah Legislative Assembly 1897).	Realization by public at large of need to recruit young fish each year to maintain fishery.
1897–1905	Approximately $133,496 wholesale fish sold from Utah Lake (estimate may be very low) (Carter 1969).	Much unreported fishing occurred.
1899	Legal to ship certain fish out of Utah, including carp, chubs, suckers, black bullhead. D. S. Jordan again visits Utah Lake, finds fishery decline (Utah Legislative Assembly 1899).	Market among eastern U.S. cities.
1899–1904	Around 500,000 lbs of fish from Utah Lake shipped out of state (Chambers 1910).	To get needed out-of-state capital.
1900–1903	Channel catfish and black bullheads introduced into Utah Lake (Popov 1949).	Attempt to get more diversified fishery.
1900–1914	Increased catch of common fish, reaching 3,500,000 lbs live weight per year. Because many fish were between 3–5 lbs, 90 percent human consumption brought premium prices in eastern U.S. cities (Chambers 1910, Chambers 1913, Carter 1969).	Beef high in cost. European and Asian immigrants prized carp.

Table 7 continued.

Date°	Activity	Possible causes
1900–1952	Gradual filling and dredging of mouth of Provo River eliminates varied habitats, reducing fish population (Loy 1972).	Construction of more permanent docking and recreational facilities, and obtaining more farm land.
1901	Legal to catch and sell fish from Utah Lake by hook and line (Sharp 1897).	
1903	Unlawful to catch trout commercially by any means (Utah Legislative Assembly 1903).	Population decline continued.
1905	Five Utah fish-selling businesses do $105,000 wholesale and $90,000 retail business within state of Utah. At least 10 percent (probably much more) came from Utah Lake (Carter 1969).	Good market for fish continues.
1905–1930	Sport fishery for large mouth bass becomes important (Carter 1969).	Development of resorts, rail connections around Utah Lake.
1907	Required commercial seining license cost varied from year to year ($1 to $25), usually $10. Royalty to state on fish seined, 15¢ to 25¢ per 100 lbs of live fish (Utah Legislative Assembly 1907).	Help regulate fishing on Utah Lake.
1909	Unlawful to commercially take large mouth bass; commercial fishing concentrates on more abundant common fishes (Utah Legislative Assembly 1909).	Slight decline in bass population; upsurge in sport or table fishing.
1909–1974	Input of Colorado basin water via Strawberry Reservoir-Spanish Fork River into Utah Lake drainage and possible introduction of fish species, e.g., speckled dace now in Utah Lake drainage (current creek) (White et al. 1969).	Desire of farmers in Spanish Fork area for more irrigation water, Strawberry Reservoir constructed.
1910	Beginning of extensive illegal seasonal set line fishery in Provo Bay and other parts of lake for channel catfish and bullhead catfish. Up to 100 participants (Carter 1969).	Ready market for dressed catfish, added to family income.
1910–1920	Perch, green sunfish, and bluegill introduced into Utah Lake (Popov 1949).	Desire for more fish species for sportsman.
1910–1974	Turbidity and silt load of Spanish Fork River increases to 11–12-month duration and eliminates much of the fishery at mouth of river (Loy 1972).	Silt from Diamond Fork's unstable water shed, dredging of stream bottom, return flow from agriculture.
1914, 1915, 1930s	Fish were siened by Utah State Fish and Game Department personnel and given to the needy (Siddoway 1918).	National and state economic depressions.
1914–1930	Carp and suckers caught to make chicken food. Live boxes used extensively. From early 1920s to early 1930s, fish for chicken food was greatest use of fish (Carter 1969).	Good chicken egg production.
1915°	Shipping fish by railroad live to eastern U.S. was not continued as freight rates became too high (Carter 1969).	Market was there but transportation costs too high.
1917	Utah state government hires more seiners to catch fish from the Lake, sold from 2¢ to 5¢/lb (Siddoway 1918).	Conservation of other meat to supply WWI efforts.

Table 7 continued.

Date°	Activity	Possible causes
1917–1920	Extensive use for human consumption; some canned.	WWI price of meat was high, short of supply.
1923	Average weight of rough fish caught below 3 lbs—market outside Utah then reduced orders (Carter 1969).	Overfishing of older year classes.
1928–1950	A small percentage of rough fish used in feeding hatchery rainbow trout. Phased out with development of all dry pellet ration (Carter 1969).	Development of extensive rainbow hatchery program by state of Utah to stock waters for sport
1929–1935	Human consumption of rough fish increases sharply. Sold in Utah and Salt Lake Valleys. Each week 3,000 lbs shipped on ice by railroad to California for human consumption (Carter 1969).	Nationwide (1929–1939) depression—Utah Lake fish very inexpensive compared to beef.
1930–1974	Input of Weber River water via Provo River into Utah Lake, and possible introduction of new genetic material, e.g., mountain whitefish population of lower Provo River shows highly variable serum electrophoretic patterns, but those of lower Weber River are very constant (Hanson 1970).	Lack of sufficient water in Provo River to meet all the irrigational demands.
1930–1974°	Destruction of spawning suckers and carp by clubs, pitchforks, etc., in the name of sport(?). Few of the fish are utilized, and elimination of spawners has further reduced the sucker populations of the lake (Liddiard 1968, White 1973).	Lack of understanding of their detrimental effect on fish population.
1932	Catch of 54,000 lbs live weight/week by fishermen sold for 1¢ to 7¢ per lb (Carter 1969).	
1932–1935	Many fish died from overcrowding and suffocation in the summer, and freezing and thawing in the winter (Hatton 1939, Liddiard 1968).	Drought reduced size of Utah Lake, irrigation demands on inflowing streams dried them up.
1932–1935	Large mouth bass population sharply declines—sport fishermen complain to state agencies.	Drought reduced bass population and reduced much of littoral habitat along with increased farming and filling of marsh habitat along eastern shore.
1932–1974	*Tamarix pentandra*, a woody plant introduced; becomes a dominant species of littoral zone. Seining for fish became more difficult and net repairs more frequent (White et al. 1969).	Water level variance greater due to lake manipulation as a reservoir; reduced or eliminated many species in littoral zone.
1933	Sharp decline in use of fish for chicken food (Carter 1969).	Development of pellets and dry mash. Though more expensive, supply more constant and less work.
1933	Development of market among mink ranchers (Carter 1969).	Mink ranching in Murray, Coalville, and Echo, Utah, becomes big business.
1934–1936	Dredging of channels in Provo Bay during drought to increase flow into Utah Lake for Salt Lake Valley irrigation (White 1964).	Claim of Utah Lake as a reservoir.
1935	Fish numbers so depleted some commercial fishermen forced out of business.	

Table 7 continued.

Date*	Activity	Possible causes
1936–1939	Well-meaning groups destroy heron gull and cormorant young and nests to reduce predation on reduced fish populations (Featherstone 1961).	Desire to save fisheries.
1936–1939	Rains return and the loose organic soils of upper Provo Bay washed into spring and lake areas of lower Provo Bay, filling area (e.g., Crystal Lake becomes known as Mud Bay) (Harrison 1962).	Suspended soil followed dredged channels.
1950	Introduction of walleye, which developed a small self-sustaining population increasingly popular with anglers, especially during early spring upriver spawning runs (Arnold 1960).	Provide better sport fishing in Utah Lake.
1952–1974	Accelerated dredging and channelization of lower Provo River. Most deep, large hole areas with protective willow and cottonwood cover are removed. Resident-fish populations reduced to very low levels, forage (minnows) fishes almost entirely eliminated, only spawning and foraging fish now commonly found in River (White 1973).	U.S. Army Corps of Engineers' flood control. Individual land owners, irrigation companies desire to control water drainage. Urbanization of stream bank.
1956	Introduction of white bass; by 1967 it had become one of most numerous fishes in Utah Lake. It is readily caught by anglers in the spring. It grows only slightly after second year of life (Vincent 1967).	Desire to provide more sport fisheries.
1969	Introduction of fathead minnow and golden shiner. Fatheads are now (1974) found in mouths of inflow streams. Golden shiners have not done well (White 1969).	To provide forage fish for the game fishes.
1974	Most native populations eliminated; a few suckers remain.	Result of irrigation, overharvest, habitat destruction.
1974	Commercial fishing on a limited scale during the winter. Carp, suckers, and black bullhead are legally taken. Little human consumption, sold to animal food processors.	Little demand for common fish.
1974	Sport fishing heavy during early spring for walleye and white bass. Spring and fall fishing for black bullheads common. Occasional channel catfish, large mouth bass taken. Localized fisheries for green sunfish and bluegills during the late spring.	Closeness of Utah Lake to Wasatch Front population centers; more leisure time and higher cost of recreation.

*Asterisk indicates approximate date.

Brigham Young was interested in obtaining fish from Utah Lake to help feed the expanding settlements in the Salt Lake Valley. In January 1849, he sent an exploring party to Utah Lake to seek out fishing places (*LDS Journal History of the Church*, 6 January 1849). Then in March 1849, the General Authorities of the LDS Church voted to send a colony to Utah Valley for the explicit purposes of farming (raise a few beavers, fish, and teach the Indians how to farm and read) (*LDS Journal History of the Church*, 10 March 1849).

On 12 March 1849, the first settlers entered Utah Valley under the leadership of John S. Higbee, who had accompanied Parley P. Pratt on the first fishing expedition (Jensen 1924). They settled on the south side of the

river and began laying out their fields and building a fort. By May, the Indians were involved in their annual fishing activities on the Provo River as the spawning fish were moving into the river. The settlers soon joined in catching them by hand. When Parley P. Pratt visited the colony in the last week of June 1849 and saw thousands of fish being caught by Indians and whites, he estimated that 5000 barrels of fish could be secured annually from the fishery (Pratt 1849). The early pioneer diaries of Utah Valley mention the fine fish from Provo River and Utah Lake (Colton 1946).

It would seem that the Indian and early pioneer fishery was of mixed species, with the cutthroat trout bringing the highest prices. A brief annotated history is given in Table 7.

Transition from Commercial Fishery to Sport Fishery

The transition from a commercial fishery to a sport fishery was the result of several related factors. The exploitation by commercial fishermen plus the destruction of the spawning grounds and habitat led to the complete destruction of the most desirable food fish in Utah Lake, the Utah cutthroat trout (*Salmo clarki*).

It became obvious by the late 1800s that some action would have to be taken to prevent the complete destruction of desirable fish in Utah Lake. The state legislature in 1897 passed a law making it illegal to take any fish by seine except carp (*Cyprinus carpio*), Utah chub (*Gila atraria*), and suckers (*Catostomus sp.*) (Carter 1969). In 1899, black bullheads (*Ictalurus melas*) and channel catfish (*Ictalurus punctatus*) were added to the list of fish that could be siened. They were dropped from the list in 1929. The 1897 law also required all mills, factories, power plants, and manufacturing concerns to screen their canals to attempt to prevent the destruction of trout. It also prohibited seining within one-half mile of the mouth of any stream during the spawning period. This law and others following it were not strictly enforced until the early 1920s and 1930s, when the commercial harvest of game fish had pretty nearly come to an end. During the early period of exploitation nearly 100 percent of the fish harvested from Utah Lake was used for human consumption (Carter 1969). As agriculture and transportation improved, the state gradually developed a more stable economy and it was no longer necessary to rely on fish as a source of food to supplement the diet of early settlers; however, by this time the cold water fishery had disappeared and was replaced by warm water species.

Biology of Utah Lake Fishes

Very meager information is available concerning population densities, production, life histories, and food habits of the fish species found in Utah Lake. Some of the fish listed in Table 5, such as the trout species, may be migrants from the streams and rivers that enter the lake.

A controversy exists regarding the species of sucker present in the lake. Hatton (1939) described three species of sucker (June sucker, Webug sucker, and Utah sucker) from Utah Lake. Collections by BYU researchers have shown at least the Utah sucker and the June sucker still exist in the Lake. Hatton (1939) also collected the mountain sucker, but no subsequent records of this species have been found. The June sucker is endemic to Utah Lake and its current status should be determined; if it is present, it should be protected and a thorough ecological study should be conducted to gain as much information about this species as possible.

The littoral zones of Utah Lake are used as reproducing and rearing areas for most of the fish in Utah Lake (White and Dabb 1970). Seining of the shallow shore areas indicated that young-of-the-year fish were abundant in these areas (Table 8). The most dominant fish

TABLE 8. Seining of shallow littoral areas of Utah Lake, Utah County, Utah, by the Utah Division of Natural Resources around 1970.

Species	Percent of total catch
White bass	70
Carp	16
Black bullhead	8
Bluegill	.6
Channel catfish	.6
Golden shiner	.6
Yellow shiner	.6
Largemouth	.6
Walleye	.6
Fathead minnow	.6

was white bass, and carp and black bullhead were quite abundant. Bluegill, channel catfish, golden shiner, yellow perch, largemouth bass, walleye, and the fathead minnow were common.

The Lincoln Bench area, with its rubble-gravel substrate, had the highest species diversity. All areas with the rubble substrate were used by the fish for reproduction and rearing areas. Bird Island was a primary site for channel catfish reproduction. Mud Lake was also utilized by channel catfish, as well as white bass, for spawning and rearing. The rocky littoral zone along the eastern shore of Goshen Bay is an important fish spawning and nursery area.

Descriptions of Fish Caught for Sport

Channel Catfish

Age and Growth: Channel catfish were introduced into Utah Lake in 1911 and have been stocked on numerous occasions since.

Lawler (1960) calculated the following lengths at ages one through 12 years based on the body length (total length)-spine radius relationship: 64, 146, 197, 256, 320, 365, 402, 457, 474, 487, and 489 mm. The length-weight relationship is expresed by the equation Log W = –4.814 + 3.025 LogL. The actual spawning season has not been definitely determined, but possibly extends from late June until September. As a result, the first year growth of channel catsifh is very slow (Lawler 1960). Carlander (1969) reported that channel catfish in turbid waters (similar to Utah Lake) over 500 acres grew at approximately the following average lengths for the years one through 11: 84, 163, 224, 277, 340, 381, 450, 472, 518, 531, and 577 mm. Fish in reservoirs reported by Carlander were growing faster and attained a greater length than channel catfish in Utah Lake.

Reproduction: Lawler (1960) found that no channel catfish had reached sexual maturity until four years of age. The percentage of fish that had reached sexual maturity from age four on was as follows: IV—9 percent, V—59 percent, VI—94 percent, VII—99 percent and VIII—100 percent. Carlander (1969) reported that Katy (1959) found in a summary of literature that channel catfish typically mature between the ages of four and six years.

In Utah Lake the majority of spawning apparently takes place in the waters surrounding Bird Island, off Lincoln Beach, and adjacent to the Knolls (Lawler 1960). These areas are honeycombed with rock outcrops and ledges. It was reported by Stewart (1968) that fairly large numbers of channel catfish moved into Mud Bay during June, July, and August and had moved out by October 16. He captured gravid females from 12 June to 27 July.

Diet: The dominant food item found in the stomachs of channel catfish in Utah Lake was fish (Lawler 1960). Fish occurred in 29 percent of the stomachs examined and comprised 84 percent of the food volume. Insects were found in 29 percent of the stomachs and crustaceans in 4 percent. Utah chub, yellow perch (*Perca flavescens*), and black bullheads were the dominant fish found in channel catfish stomachs. Smaller catfish fed heavily on Diptera larvae. Brown (1968) examined several species of fish taken by seine in January 1968 and found that chironomid larvae were the dominant food items in all species, including channel catfish. Channel catfish examined by Dabb and Thompson (1975) ranged from 35 to 372 mm, with one fish 613 mm long. Fish taken in both the littoral and pelagic areas of the lakes were depending heavily on chironomids for food. The one large fish examined contained the remains of three carp. The forage food base for larger channel catfish has been reduced since Lawler's work; Utah chub and yellow perch are now very rare in the lake.

Harvest: The channel catfish population has apparently declined considerably since 1960, when Lawler reported his work. In 1958 and 1959, respectively, a fisherman catch rate of 0.40 and 0.45 fish per hour was reported. Arnold (1958, 1959) reported a gill net catch rate of 0.47 and 0.25 fish per hour for the two years 1958 and 1959. White and Dabb (1970) duplicated Arnold's gill net work and caught 0.03 channel catfish per hour. Fishermen in 1970 were taking channel catfish at the rate of 0.05 fish per hour (Utah State Division of Wildlife Resources 1970).

Black Bullhead

Age and Growth: Black bullheads were introduced into Utah Lake in 1871 (Popov and Low 1950). Their population has fluctuated through the years and is presently one of the largest in the lake. Bullheads in the lake exhibit an explosive growth rate in the first two years of life and attain a maximum size by the end of their second year. After age two they grow very little (0.5 to 1.7 percent mean annual increment) (Thompson and Dabb 1974). Calculated total lengths based on aging by spine section were 131, 292, 292, and 295 mm for the ages one through four (Thompson and Dabb 1974). This growth compares favorably with bullhead growth in Iowa and Oklahoma waters (Carlander 1968).

Reproduction: No research has been done on bullheads in Utah Lake to determine age at maturity or time of spawning. However, spawning activity has been observed typically during the month of July. Sigler and Miller (1963) state that spawning typically occurs when water temperature warms to between 65 and 75 F.

Diet: Brown (1968) reported that chironomids were the dominant food item in bullheads taken near Lincoln Beach in January 1968. A total of 211 black bullheads were collected from May to October 1974 and their stomach contents examined (Dabb and Thompson 1975). They exhibit the most diversified diet of any game fish in the lake, utilizing 11 different food items. Both juveniles and adults fed prominantly on chironomids. They secondarily utilized copepods in May and June and changed to *Leptodora kindtii* during July, August, and October. Kutkuhn (1955, 1958) reported that, along with insects and zooplankton, fish and frogs were an important part of the bullhead diet in Iowa lakes. No fish were found in the stomachs of bullheads in Utah Lake.

Movements: Movement of black bullheads was studied using radio telemetry in 1973 (Thompson and Dabb 1974). They appear to occupy a rather restricted though large area of the lake for some time and then move to another. Movement is generally associated with wind and wave action. One bullhead was tracked under the ice in January and February for 336 hours. It moved a distance of only 900 feet and occupied an area of approximately 4 acres (Thompson and Dabb 1974). Another bullhead tracked for 485 hours in April and May moved 13,900 feet and occupied an area of 63 acres. A third bullhead tracked for 244 hours moved a distance of 59,800 feet and occupied an area of 1550 acres. Movement was generally restricted to a particular bay and was generally fairly close to shore. Bullheads were constantly moving.

Harvest: Black bullheads were the fish most commonly caught by fishermen in Utah Lake. The catch rate during the summer months of 1970 averaged 1.5 fish per hour and ranged from 0.40 to 2.60 fish per hour (Utah Division of Wildlife Resources 1970). The average bullhead catch rate in 1958 and 1959 was 0.38 fish per hour and ranged from 0.13 to 1.04 fish per hour (Arnold 1958). The gill net catch rate in 1958 and 1959 was 0.12 fish per hour compared to 0.74 fish per hour in 1970 (White and Dabb 1970). The bullhead population was probably larger, based on these data in 1970, than it was in the late 1950s.

Large Mouth Bass

The large mouth bass (*Micropterus salmoides*) population boomed following its introduction in 1890 and was very important to the commercial fishermen. Commercial harvest of largemouth bass increased to approximately 65,000 pounds by 1900 and then steadily declined (Carter 1969). During the winter of 1924–25 tons of large mouth bass washed ashore as a result of oxygen depletion. During the winters of 1959–60 there were many reports of dead large mouth bass. At the present time their population is very small, with only an occasional fish being taken by fishermen and biologists. During the summer of 1970, only four large mouth bass were checked by creel clerks. No research has been done on this valuable sport fish to determine the reason for its failure to succeed, and research is needed to determine if success with this species could be achieved.

Walleye

Age-Growth: Walleye were first introduced into Utah Lake in 1952 and were subsequently introduced in 1954, 1955, and

1956. Arnold (1960) reported that walleye grew to the following average sizes for ages one through six: 169, 290, 330, 374, 389, and 399 mm for males; and 172, 298, 347, 395, 440, and 465 mm for females. The length-weight relationship is expressed by the equation Log W = –4.79031 + 3.02554 Log L. Cleary (1948) reported the following lengths at the end of years one through six: 124, 230, 308, 364, 409, and 454 mm for walleye in Clear Lake, Iowa. Walleye grew faster in Utah Lake for the first four years and were then surpassed by the Clear Lake fish.

Reproduction: Walleye in Utah Lake begin spawning at two years of age for males and three years of age for females. However, a majority of the spawners are from three to five years old. Walleye typically begin spawning by about mid-March and continue until mid-April. Sakamoto and White (1974) obtained six males and nine females from the Division of Wildlife Resources and undertook a fecundity study. Males examined ranged in age from five to eight years and females from seven to ten years. Fecundity of fish they examined increased with fish length. Calculated fecundity of fish 400 mm long was 12,500 eggs per female. Walleye 700 mm long had a calculated fecundity of 257,800 eggs. The range in fecundity of fish examined was 46,524 to 227,138 eggs per female.

During recent years the Utah Division of Wildlife Resources has attempted to increase the walleye population in Utah Lake because of its growing popularity with fishermen. Walleye running the Provo River were captured and spawned artificially, the eggs were hatched at one of the state hatcheries, and the fry were returned to the lake. The division collected 11.0, 21.9, 21.0, 31.6, and 14.9 million eggs during each of the years 1972 through 1976. The Springville State Fish Hatchery, where most of the eggs have been incubated, has been successful in hatching approximately 50 percent of these eggs.

Diet: Arnold (1960) reported the four species of forage fish comprised 63.5 percent of all identified food found in walleye stomachs. These were redsided shiner, yellow perch, Utah chub, and carp. Most of the stomachs that Arnold examined came from fish that were from 400 to 500 mm long. Brown (1968) found chironomids to be the dominant food item in walleye taken in January 1968 near Lincoln Beach. Dabb and Thompson (1975) examined walleye stomachs of fish ranging in size from 123 to 474 mm. Smaller fish (range 234 to 360 mm) were dependent on chironomids, copepods, and liptodorans. Their diet studies did not include fish taken during the months of June and July. Walleye taken from August through October (size range 157 to 474 mm) contained 100 percent fish, consisting of carp, white bass, and channel catfish. Redsided shiner, Utah chub, and yellow perch are now rarely found in the lake. This lack of forage fish is undoubtedly having an adverse effect on the growth of walleye.

Harvest: The fisherman harvest of walleye was very light during the late 1950s; practically no fish were taken (Arnold 1960). During recent years (1970–1973) the Division of Wildlife Resources has measured fisherman harvest during the spawning run in March on the Provo River and in the vicinity of the Utah Lake State Boat Park, during which time fisherman hours increased from 6169 in 1970 to 11,198 in 1973. The walleye harvest increased from 1313 in 1970 to 1558 in 1973. The yearly average catch rate for walleye in 1970 was 0.002 fish per hour, excluding the harvest associated with the spawning period. Gill net catch data indicates that the population has changed little since 1958–59. Arnold (1958) took an average of 0.12 and 0.08 fish per hour in gill nets in 1958 and 1959, respectively. White and Dabb (1970) caught 0.08 fish per hour in duplicating Arnold's work. Though no data have been collected, it is apparent that fisherman pressure and success have improved at other locations on the lake, such as the Geneva-Orem boat harbor area, the mouth of the Spanish Fork River, and Lincoln Beach. Walleye harvest remains seasonal and in conjunction with spawning activities, but angler awareness of this prized game fish is increasing.

White Bass

Age-Growth: White bass were introduced to Utah Lake in 1956 when 209 fish were transplated from Colorado (Vincent 1967).

White bass in Utah Lake attained lengths as follows at the end of each year of life: 96, 164, 211, 249, 281, and 291 mm (Trapnell

1969). By comparison, white bass in Oklahoma reach the following lengths at the end of each year: 193, 310, 366, 417, 434, and 452 mm. In an Iowa study white bass grew as follows: 132, 246, 300, 345, 388, and 429 mm (Sigler and Miller 1963). It is apparent that white bass in Utah Lake grow at a slower rate than fish in these two waters. White bass in Utah Lake also show very little growth after their fourth year.

Reproduction: Vincent (1967) reported that mature male white bass began to school up in the spawning areas near Bird Island and Lincoln Beach by mid-April, when the water temperature reached 52 F. Extensive schools of female white bass were never noted, though relatively small numbers of gravid females, compared to numbers of males, were taken throughout the spawning period. Vincent (1967) identified the primary spawning area for white bass to be Lincoln Beach. He also concluded that most actual spawning occurred about mid-June. Vincent did not determine the age of white bass in Utah Lake at the time of sexual maturity, however; typically, white bass mature in their second year of life and a few in their third, but none in their first (Sigler and Miller 1963).

Diets: Young-of-the-year white bass fed primarily on zooplankton, whereas larger fish were dependent on aquatic insects, mainly chironomids (Trapnell 1969). Dabb and Thompson (1975) collected 196 white bass stomachs from May through October 1975. Small white bass (less than 199 mm) fed primarily on copepods in all months but August, when they relied heavily on *Leptodora kindtii*. Larger white bass (greater than 200 mm) fed on copepods in May and June then switched to *L. kindtii* as the primary food during the remaining months. Chironomids were also important to white bass of all sizes. Fish were noticeably absent from the diet of white bass taken in pelagic water. Fish collected in littoral areas of the lake in August were dependent on zooplankton and chironomids; however, a few were feeding on young-of-the-year white bass. These fish typically feed on forage fish after their first year (Webb and Mobb 1967). It appears that the lack of a suitable forage fish in Utah Lake is probably the limiting factor for growth.

Harvest: Very few white bass were taken by boat fishermen on Utah Lake (White and Dabb 1970). During the spring there was an active fishery for them at the mouth of the Provo River. As many as 200 fishermen would often fish under the lights at the boat harbor. Occasionally, catch rates of 10 to 12 fish per hour were attained. The general size of the white bass taken by fishermen was approximately eight to ten inches. The summer catch reported by White and Dabb (1970) was only 0.08 fish per hour, ranging from 0.01 to 1.56 fish per hour.

Forage Instructions: The probable reason for the demise of the sport fish in Utah Lake is that they are predacious on other fish and there are no suitable forage fish in the lake. In 1969 the Utah Division of Wildlife Resources introduced approximately 90,000 fathead minnows (*Piemephales promelas*) and 90,000 golden shiners (*Notemigonus crysoleucas*) into the lake in an attempt to provide this needed forage base. In 1970, golden shiners were occasionally taken in gill nets and both golden shiner and fathead minnows were taken by siening. Golden shiners and fathead minnows were not collected during extensive travel and seine work in 1975. It is assumed that these two species will not succeed as a forage base for the sport fish in Utah Lake.

Population Changes

Arnold (1958), working for the Utah Division of Wildlife Resources, undertook an extensive gill netting program in an attempt to understand relative population abundance. His efforts were duplicated by White and Dabb (1970). Table 1 lists the species taken in gill nets during the two studies in order of decreasing abundance for comparison.

Lowder (1951) reported that the three suckers (*Chasmistes liorus*, *Catostomus fecundis*, and *Catostomus ardens* were all found in Utah Lake in 1951 and that the decreasing order of relative abundance of fish species in 1951 was carp, sucker, catfish, perch, Utah chub, and largemouth bass. The sucker population was one of the largest in the lake in early history. However, overexploitation, habitat destruction, and the drought of 1932–1935 greatly reduced this

population and it has never returned to its previous size.

The fisherman catch composition in 1958 was channel catfish 60 percent, black bullheads 30 percent, carp 7 percent, and yellow perch 3 percent. The fisherman catch in 1970 consisted of black bullhead 89 percent, channel catfish 3.4 percent, white bass 2.6 percent, carp 2.0 percent, and largemouth bass, yellow perch, and walleye 0.6 percent each. The average catch rate in 1958 was 0.77 fish per hour, and in 1970 the average catch rate was 1.66 fish per hour. The large increase in catch rate was the result of the increase in black bullhead harvest.

During this period the Utah chub has decreased from the second most abundant fish in gill net catches to nothing, and the yellow perch has decreased from fourth most abundant to nothing. The white bass has increased from last to most common species taken in gill nets. The black bullhead has replaced the channel catfish as the dominant fish in the fisherman's creel. Utah Lake has a dynamic fishery that must be continually monitored and managed if it is to remain productive.

Pesticide Levels in Utah Lake Fish

The Food and Drug Administration has set the following acceptable levels for pesticides and mercury: Dieldrin 0.30 ppm, DDT 5.0 ppm, DDE 7.0 ppm, PCB's no level set, and mercury 0.5 ppm (Smith 1973). Carp and black bullhead catfish in Utah Lake were tested in 1973 (Smith 1973). White bass tissue was analyzed for the Bureau of Sport Fisheries and Wildlife by WARF Institute, Incorporated, Madison, Wisconsin, in 1970. Levels of pesticides and mercury in wet muscle tissue are tabulated in Table 2. No fish sampled exceeded any of the levels that have been set.

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TERRESTRIAL VERTEBRATES IN THE ENVIRONS OF UTAH LAKE

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Abstract.— From an historical aspect, there are or have been 215 species and 62 families of terrestrial vertebrates found in the environs of Utah Lake. The classes Amphibia and Reptilia are represented by 4 species in 3 families and 12 species in 4 families, respectively. The class Aves has the highest numbers of species and families. The birds are represented by 152 species and 39 families. There are 47 species of mammals found within 16 families. Three additional species of reptiles have been reported to one of us by the Division of Wildlife Resources personnel as occurring in the environs of Utah Lake, but these are not recorded in the literature and have not been verified by us.

The terrestrial vertebrates (amphibians, reptiles, birds, and mammals) comprise an integral part of the fauna on and around Utah Lake. Birds are the most numerous, are more frequently observed, and create a greater impact on the lake than amphibians, reptiles, and mammals. However, each group represents an important component of the vertebrate fauna associated with this body of water. The information on these vertebrates is arranged in the usual phylogenetic order, with biological data on the various species and, wherever it is available, information concerning the historical aspects.

The tetrapod fauna of the environs of Utah Lake include four species of amphibians representing 3 families, 12 species of reptiles in 4 families, 152 species of birds representing 39 families, and 47 species of mammals found within 16 families. The total tetrapod fauna found in and around the lake consists of 215 species within 62 families.

Amphibians and Reptiles

In the environs of Utah Lake, there are three distinct communities that provide habitat for amphibians and reptiles, viz., grassy meadows at or near the shoreline, rivers and other permanent streams, and the dry shoreline along the west side. Each community contains certain species that are distinct from those in the other communities.

Grassy Meadows Near or at the Shoreline

Four species of amphibians and two of reptiles occur in this habitat. Some of them are wide ranging species that occur in other areas. They are, however, common in the shoreline meadows.

Bufo woodhousei woodhousei **Girard.** Woodhouse's Toad. This is perhaps the least common annuran in the meadows. It occurs there primarily during the breeding season, but it is in the surrounding fields and gardens during the summer. This is a ravenous insect feeder and may be found under street lights on warm evenings feeding on the insects attracted to the light.

Pseudacris nigrita triseriata **Wied.** Western Chorus Frog. This species is common throughout the meadows of Utah and ranges from the low valleys such as Utah Valley to the high mountain valleys up to 10,000 feet. In Utah Valley, it is abundant in the meadows around the lake. In April and May breeding choruses occur in standing water in fields, meadows, ditches, etc. Eggs are layed in clusters and are usually entangled in the submerged vegetation.

Rana pipiens brachycephala **Cope.** Western Leopard Frog. This is perhaps the most widespread and abundant amphibian in Utah. Large numbers of them occur in the meadows and fields surrounding Utah Lake. Slow-moving streams and meadow ponds serve as

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the breeding areas. After breeding the adults disperse widely in the meadows and adjoining fields in search of food. Only moist ground or seepages are required to provide their water requirements. In this regard, the leopard frog is only slightly more dependent on moisture than our *Bufo*.

Because of its adaptive versatility, this frog may be found in all moist habitat niches from the shoreline into the meadows, along drainage ditches, permanent streams from springs and rivers, and into the adjoining irrigated fields.

***Rana pretiosa pretiosa* Baird and Girard.** Western Spotted Frog. This frog is more selective of its habitat, occurring primarily in the near vicinity of emerging spring water. It is not generally found in open meadows unless there is a large spring providing the water flow. It has been found in the springs and for a short distance down from them all along the Provo River and its adjacent meadows and springs. Breeding populations have been found from the North Fork of Provo River to springs near Utah Lake. This is a more secretive species, more apt to be sitting in the water than on the bank. Therefore, they need only to submerge to disappear. The characteristic splash of the leopard frog as it leaves the bank for the water is rarely heard in the spotted frog. Because of its preference for cool springs, this frog is not widespread in the meadows surrounding Utah Lake. They are not rare, but occur in reasonable numbers in their habitat niche.

***Thamnophis elegans vagrans* Baird and Girard.** Wandering Garter Snake. This snake is widely distributed throughout the meadows and along streams. It is not restricted to water or moist habitats, but is apparently found in these areas because of the abundance of food. For example, in the meadows are frogs and field mice for the adults and, for the young, numerous insects and other invertebrates, as well as fish along streams and the lake shoreline. Since this snake is a generalized feeder, the mesic habitat offers not only a great variety of food but an abundance.

Thamnophis sirtalis parietalis Say. Red-sided Garter Snake. This snake is restricted primarily to the meadows surrounding the lake. They are rarely found in cultivated fields or dry meadows. From the Provo Boat Harbor north to the old Geneva Resort area they occur in the meadows and in shoreline vegetation along the lake. In this habitat, they are more abundant than the wandering garter snake, although both occur in the same habitat.

It lives in a more aquatic habitat than the wandering garter snake and is thought to feed more frequently on amphibians and fish. Because of its fish-eating habits, individuals are occasionally found along Provo River well above the area of the shoreline meadows.

River and Permanent Stream Habitats

Rivers and some streams enter the lake and provide willow and bank habitats quite different in their basic nature to that found in the open shoreline meadows and adjacent fields. These differences provide opportunity for a few other species to approach the vicinity of Utah Lake.

***Coluber constrictor mormon* Baird and Girard.** Western Racer. In the willow thickets along the rivers this snake may be found, often nearly to the shoreline. The willow habitat attracts small birds and other species of small rodents not found in the meadows. Thus, a new habitat niche is established as a finger extending through the meadows to the lake. In this area, a different food chain is established, with the racer preying on small birds and those species of rodents (such as *Peromyscus*) that enter this habitat.

***Pituophis catenifer deserticola* Stejneger.** Great Basin Gopher Snake. Whether this snake extends its range west along Provo River to Utah Lake is not known, but it is a distinct possibility. It has been seen along the Provo River, west of Provo.

Shoreline on West Side of Utah Lake

Little water enters the lake from the west; thus the meadows on the western shore are narrow and merge into the rocky foothills often awash with lake water.

Few reptiles seen near the shoreline on the east side of the lake are also present on the west side. Several species of lizard (*Uta, Sceloporus, Cnemidophorus, Phrynosoma*) have been seen near the water, and several snakes (particularly *Pituophis, Masticophis,*

Fig. 1. Great Blue Heron. Photo by R. J. Erwin.

and *Coluber*) are found above the shoreline in the grasses and low-growing shrubs near the lake.

In the meadows southwest of the Saratoga Resort, there was at one time a large population of *Pituophis*, *Masticophis*, *Coluber*, *Hypsiglena*, and *Crotalus* that fed largely on mice and/or lizards during the summer and hibernated in a ledge a short distance to the southwest. We have seen *Pituophis* moving from the den to the meadow, and Pack (1920?) reports an experience at the time some of these meadows were being harvested for hay. Gopher snakes were present and feeding on numerous mice.

We must recognize that the west side of Utah Lake has a very different shoreline compared to that of the east. Because of its greater slope, it provides less meadow and thus fewer (but the same species) amphibians but a greater variety of reptiles (both lizards and snakes) that utilize the shoreline habitat.

There are few streams or springs entering the lake from the west side. This fact and the steeper slope reduce the meadows along the shoreline and permit the desert shrub habitat to descend from the foothills to or near the water's edge. Thus, reptiles not normally seen near water may occur within a few feet of it. Because the lake has a fluctuating level, the condition described above usually occurs during the spring or early summer, when the water level is at its maximum.

Two students working for the Division of Wildlife Resources reported that they collected two species of amphibians in the envi-

rons of Utah Lake that were not reported in this paper. They collected the bullfrog, *Rana catesbeiana*, at Lincoln Beach, Powell Slough, and the Provo Airport and the western toad, *Bufo boreas*, at Genola Warmsprings. These species have not been verified by us, but there is no reason to believe they should not occur in these areas. The bullfrog is an introduced species in Utah; the other species is native.

MAMMALS

Each species of living organism has adapted through time to a particular type of habitat. Each species of mammal found in or near Utah Lake is there because its requirements for food, shelter, courtship, and the rearing of young are available.

Human activities often provide new types of habitats that allow additional species to inhabit a region. Frequently these are undesirable animals that may cause damage to property or to man himself. Chief among these are old world rats and mice that are pests of houses, farms, and garbage dumps. In some cases the rats may be vectors of disease.

Not infrequently human activities or environmental change may modify the habitat to the extent that some animals cannot continue to exist; for example, the beaver and mink, once abundant in Utah Lake (Chavez and Warner 1976), are now limited in number (Wm. Davis, pers. comm.). To the best of our knowledge, in April 1976 there were only two active beaver lodges in the environs of Utah Lake. Both of them were in the willow trees on the east shore of Provo Bay. The drought during the winter of 1976–77 may have driven these animals out, because since then there has been no beaver activity around either lodge. The last verified observation of a wild mink near the lake was made by Dr. Stephen D. Durrant (pers. comm.) on the Orem Boat Harbor in the early 1960s. There are occasional reports of mink observations near the lake, but they usually turn out to be animals that have escaped captivity.

There are 44 known native wild mammalian species living around Utah Lake (Table 1). They include: one insectivore, 8 bats, 3 rabbits, 23 rodents, 8 carnivores, and the mule deer. Due to their secretive nature or nocturnal habits, we do not often see many of these animals. Table 1 provides an estimate of the relative abundance of each species and the type of habitat in which they are usually found.

In addition to those native wild mammals listed in Table 1, there are three introduced species, viz., house mouse (*Mus musculus*), norway rat (Rattus norvegicus), and raccoon (*Procyon lotor*). The first two live in close association with man in houses, out-buildings, and open garbage pits. Both are destructive to property and stored food products. The raccoon seldom occurs far from water, which seems to have limited its natural dispersal throughout our semiarid state even though it is found in the Raft River and Uinta Mountains and southwestern Washington County. It has been reported that several pair were released near the northeast shore of Utah Lake several years ago. Since their release there have been many reports of raccoon observations on the east side of the lake.

Historically, bison were found around Utah Lake. Dominguez and Velez de Escalante (Chavez and Warner 1976:60) recorded in their journal that bison were "... not too far away ..." from the lake. Coues and Yarrow (1875), on a geographic survey through Utah Valley 100 years after Dominguez and Velez de Escalante, made the following comment concerning the bison and Utah Lake [p. 68]:

> Formerly quite common in Utah as it is still remembered by the older Indians. We were informed by Mr. Peter Madsen, an intelligent fisherman, of Utah Lake, that in drawing his nets in that body of water he has frequently hauled up the skulls of Buffaloes [*sic*] and it is supposed that they were driven across the plains by the Indians upon the ice in the winter season, they broke through and were drowned.

Economically the muskrat has been the most important fur-bearing mammal in Utah Valley. Most muskrats have been collected in the region surrounding Utah Lake, but accurate records are not available for the number collected. However, some idea of the economic impact of these has been obtained from local trappers and fur buyers. These people indicate that the loss of habitat has almost destroyed the fur business in Utah Valley. The trappers indicated that 15 years ago

TABLE 1. Native mammals of Utah Lake, their relative abundance, and the type of habitat they usually prefer. Relative abundance: A = abundant; C = common; U = uncommon; Ca = casual; R = rare; E = extinct.

Name	Relative abundance	Marshlands sloughs	Grass pastures	Riparian—trees and willows	Dry brushland west of Utah Lake
Vagrant Shrew *Sorex vagrans*	C	X	X	X	
Big Myotis *Myotis lucifugus*	C				
Hairy-winged Myotis *Myotis volans*	U				
Silvery-haired Bat *Lasionycteris noctivagans*	C				
Big Brown Bat *Eptesicus fuscus*	C				
Hoary Bat *Lasiurus cinereus*	C				
Long-eared Bat *Plecotus townsendii*	U				
Spotted Bat *Euderma maculatum*	R				
Brazilian Free-tailed Bat *Tadarida brasiliensis*	C				
Black-tailed Jackrabbit *Lepus californicus*	C				X
Nuttall Cottontail *Sylvilagus nuttallii*	C			X	X
Pigmy Rabbit *Sylvilagus idahoensis*	Ca				X
Yellow-bellied Marmot *Marmota flaviventer*	U				X
Townsend Ground Squirrel *Spermophilus townsendii*	A		X		X
Uinta Ground Squirrel *Spermophilus armatus*	C		X		X
Rock Squirrel *Spermophilus veriegatus*	C		X	X	X
Antelope Ground Squirrel *Ammonspermophilus leacurus*	C				X
Least Chipmunk *Eutamias minimus*	C			X	X
Botta Pocket Gopher *Thomomys bottae*	C		X		
Great Basin Pocket Mouse *Perognathus parvus*	U				X
Ord Kangaroo Rat *Dipodomys ordii*	C				X
Chisel-toothed Kangaroo Rat *Dipodomys microps*	U				X
Harvest Mouse *Reithrodontomys megalotis*	C		X		X
Deer Mouse *Peromyscus maniculatus*	A	X	X	X	X
Pinyon Mouse *Peromyscus truei*	U				X
Northern Grasshopper Mouse *Onychomys leucogaster*	U				X
Desert Wood Rat *Neotoma lepida*	C			X	X
Bushy-tailed Wood Rat *Neotoma cinerea*	C				X
Sagebrush Vole *Lagurus curtatus*	Ca				X

Table 1 continued.

Name	Relative abundance	Marshlands sloughs	Grass pastures	Riparian—trees and willows	Dry brushland west of Utah Lake
Muskrat *Ondatra zibethicus*	C	X		X	
Pennsylvanian Meadow Mouse *Microtus pennsylvanicus*	C	X	X	X	
Montane Meadow Mouse *Microtus montanus*	C	X	X	X	
Long-tailed Meadow Mouse *Microtus longicaudus*	U	X	X	X	
Beaver *Castor canadensis*	Ca	X		X	
Porcupine *Erethizon dorsatum*	U			X	X
Coyote *Canis latrans*	C	X	X		X
Kit Fox *Vulpes macrotis*	U				X
Long-tailed Weasel *Mustela frenata*	C	X	X	X	X
Mink *Mustela vison*	R			X	
Badger *Taxidea taxus*	U		X	X	X
Striped Skunk *Mephitis mephitis*	C	X	X	X	
Spotted Skunk *Spilogale gracilis*	U		X	X	
Bobcat *Lynx rufus*	U			X	X
Mule Deer *Odocoileus hemionus*	C			X	X

there were 20 to 30 major trappers working the environs of Utah Lake. During the 1976–77 season there were 10. In addition to these men, there have been up to 100 young boys also trapping muskrats.

One of the trappers indicates that he now traps 15 to 20 "rats" with the same effort that it took him to trap 200 to 250 10 years ago. In times past he would trap about 8000 muskrats per year; last year he trapped just over 800.

The decrease in available wild furs nationwide has also had an impact on the price of muskrats. The lowest price they could remember was 19¢ for large prime pelts. The current rate is $4.40 for the same pelt.

Birds

Utah Lake is the largest natural freshwater body in Utah. It is a shallow lake with shoreline communities varying from swampy areas with emergent vegetation to rocky and sandy beaches. The various plant communities as well as the beaches provide valuable habitat for many species of birds. Although Utah Lake is probably not as productive an area for birds now as it was before the white man came to the valley, it is still an important resource for avian species.

Dominguez and Velez de Escalante, on their expedition of 1776, are credited with being the first white men to see Utah Lake. In their journal (Chavez and Warner, 1976:60) the following description is given:

> This one of the Timpanogotzis abounds in several species of good fish, *geese*, beavers, and other amphibious creatures which we did not have the opportunity to see. Round about it reside the Indians mentioned, who live on the lake's abundant fish, whence the Sabuagana Yutas called them Fish-eaters. Besides this, they gather

Fig. 2. Double-crested Cormorant. Photo, United States Steel Corporation.

the seeds of wild plants in the bottoms and make a gruel from them which they supplement with game of jack-rabbits, coneys, and *fowl, of which there is a great abundance here*. They also have bison handy not too far away to the north-northwest, but fear of the Comanches prevents them from hunting them [italics added].

Shortly after the Mormon pioneers entered the Salt Lake Valley in 1847, exploring parties were sent out to scout the area for future settlements because more people were expected to come west. Utah Valley and Utah Lake were seen and explored during the first year the pioneers were in the Great Basin. The early pioneer diaries of those who settled Provo and the surrounding areas attest to the abundance of fish and waterfowl in and around the lake.

The settling of Utah Valley had had a marked effect on animal populations in the valley and in the lake. The avian species using the lake and the surrounding areas have probably been disturbed as much as any of the organisms, with the exception of the fish within the lake. Most of the changes in the avian populations have been due to the encroachment of man upon the breeding and feeding habitats. In one or two instances, human agricultural activities have provided more habitat suitable for breeding and feeding purposes. When the settlers first came to the valley they were probably very few Robins as compared to present-day populations. Agricultural use of the land has been helpful in providing habitat for the introduced Ring-necked Pheasant and has provided a larger breeding and feeding area for the native Western Meadowlark.

Habitat and Species Destruction

As more and more people settled in the valley, five conditions arose that were harmful to many species of birds found on and around Utah Lake: (1) Until about 1960 raw sewage from the many cities and towns around the lake was dumped into its waters without any treatment. As the water became highly polluted the effectiveness of the lake as a habitat for birds decreased. Pollution in the lake has been reduced now that sewage treatment facilities have been constructed by the municipalities that dump their wastewater into the lake. (2) As the population of the valley increased, industrial organizations were attracted to the valley. Their by-products, including hot water, were frequently discharged either directly into the lake or into streams that emptied into it. In recent years much effort has been expended by the various industrial establishments to curtail harmful products and thermal pollution from entering the lake. (3) Another condition that had an adverse effect on Utah Lake bird populations was the erroneous belief that many of the fish-eating species were feeding on the game fish of the lake. There was actually a drive to exterminate fish-eating birds. This was published in the local newspapers during the 1930s. (4) Around the turn of the century market hunting was a way of obtaining a livelihood for many individuals who lived near bodies of water that supported duck populations. Utah Lake was no exception, and a number of the local residents derived their income from hunting ducks, geese, and shore birds. (5) Probably the most consistent adverse factor has been the continuous harassment of nesting and feeding species by many individuals, both singly and collectively.

During the 1930s Robert G. Bee, a local amateur naturalist, became interested in obtaining from some of the older residents of Utah Valley their recollections of the lake and its fish and bird life. By interviewing a number of men who had fished, trapped, and hunted on and around the lake he assembled some interesting information. These interviews, plus his field notes that he kept over the years, are in the Monte L. Bean Life Science Museum at Brigham Young University (Bee 1924–1962). The following paragraphs summarize information concerning the killing of fish-eating birds, market hunting, and general harassment of the birds at Utah Lake.

During the last decade of the nineteenth century and continuing well into the third decade of this century the killing of many fish-eating birds was considered to be a conservation measure. Bounties were fixed by many of the fish and game departments in the various states and, upon presenting the heads or feet of the offending species to the game officers, the bounty was paid. Bee (1930–1940) records the following from Gus Slade of Lehi, Utah:

> In the year 1896 or 7 there was a bounty paid on fish-eating birds: heron [probably Great Blue Heron], pelican, bittern, quok [probably Black-crowned Night Heron], fish duck [Mergansers], hell divers [probably Western Grebe], loon, black-gebe [probably White-faced Ibis], coromorant (*sic*). At one time the heron [probably

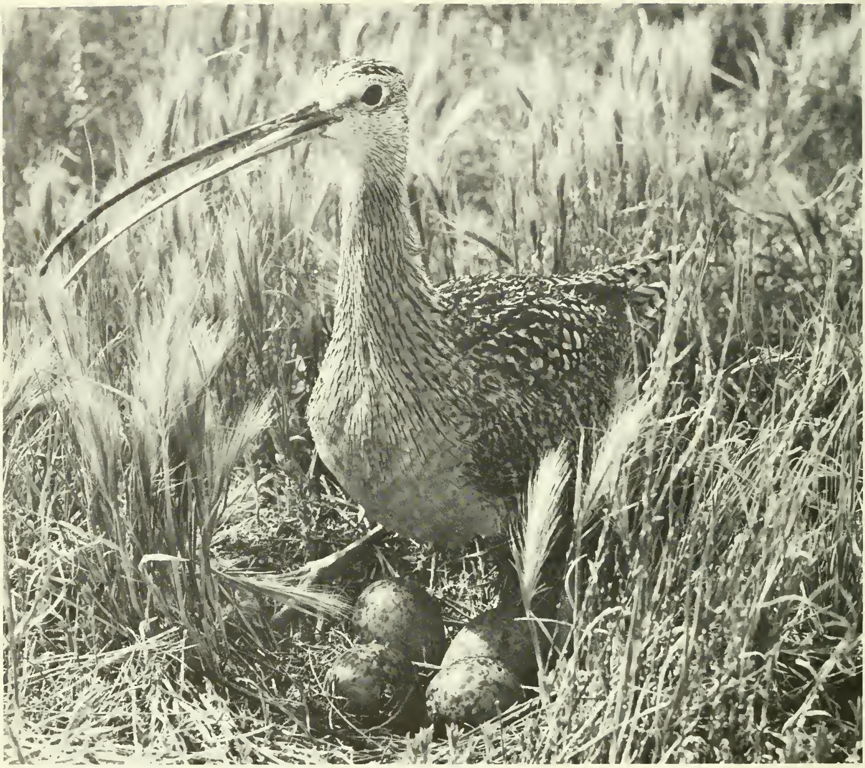

Fig. 3. Long-billed Curlew. Photo by R. J. Erwin.

Great Blue Heron] was so numerous that they used the cedar trees for nesting. In 1882 their colonies covered an area of three or four miles long and a mile or so wide in a solid mass. There were probably 100,000 of them along a low ridge in the vicinity of Soldier Pass and Goshen Pass. Al Jorgensen, Jake Westphal and myself went to a colony of the Blue Heron in the Goshen Slough. Water was about one and half feet deep. Where the rookery was the rushes, about seven feet high, were matted down to the level of the water. We took our pants off and begun work. Breaking their necks with a stick we cut their heads off, placed them in sacks, and loaded them into boats. There were four or five acres of these birds and their heads were erect like so many sticks. We loaded 1,290 heads for which we received $129.00 bounty.

This was not an isolated instance of bounty hunting. Ad Robbins of Provo related to Bee that:

Asa Carter and I made the biggest money on the lake killing "quoks" and cranes [Black-crowned Night Herons and Great Blue Herons]. . . . we were at the rookery before daylight collecting heads and eggs. At daylight we begun to shoot. . . . About the year 1890 George Hone, R. A. Barney, W. Sapfford and myself killed nesting pelicans. Never saw a worse mess in all my life. There were about 1,000 of them until the smell made us all sick [this was at Rock Island, Utah Lake].

At a later date Goodwin (1904) visited the colony and hinted that there might have been harassment of the pelicans prior to his visit. He stated (p. 127):

The first thing that forced itself upon our attention, even before we landed was the dreadful nauseating odor. With dead birds, old and young, *by the scores* scattered over the island. . . . [italics added]

In colonial species it is not uncommon to see a few young and adults dead, the result of natural mortality, but not to find "scores" as Goodwin stated. He mentioned that other in-

dividuals had visited the colony a few days prior to his visit so that the possibility of killing should not be ruled out.

Pete Johnson, of Provo, indicated that he could average \$6–\$7 per day by killing fish-eating birds and obtaining the bounty for them. He indicated that Jake Westphal (mentioned above) made from \$41 to \$42 per day from the bounty.

Another one of the early hunters (Claude Carter) reported:

> There was a bounty paid on cranes and heron in 1895. Two men could make as high as \$66 a day. Wading into the rookeries with their pants off they would crack the heron over the head. When the bounty was paid on pelican we would use a fish float tide to a wad of rushes. Gulls were also caught. There has been 10,000 slaughtered. At the Big Channel gulls have been shot and there are four or five hundred pelicans which have been shot. In 1928 I killed 1,240 mudhens [Coot]. We would eat the hearts and gizzards, take the feathers and oil, and discard the rest.

The amount of destruction carried on in the name of conservation will probably never be really known.

Concurrently with the destruction of fish-eating species was market hunting of waterfowl. This was a widespread activity in the United States at the turn of the century. Many of the individuals involved in bounty hunting on Utah Lake were also the market hunters. Mr. Slade indicated that on good days he could shoot from 125 to 150 ducks per day. A number of the other market hunters indicated from their experience that this was too high. Averaging five hunters' figures ranging from Slade's 125 per day to 35 per day gives a mean of about 75 ducks per day per hunter. We do not know how many people were involved in this activity, but one can see that if a dozen or more men were market hunting on Utah Lake the take could be from 900 to 1000 birds per day. Prices varied with the size of the ducks. Smaller teal averaged about \$1.00 to \$1.25 per dozen, and the larger ducks went for \$1.75 to \$2.00 per dozen. Feathers were also sold for around 60¢ per pound. Ad Robbins gives us an interesting picture of the daily activities of a market hunter:

> I would hunt until 10 a.m. and pack the kill 1½ miles. Then I would pick the ducks and load 50, 70, or 100 shells until two or three o'clock in the morning. Then I would go to the boat and sleep until it was light enough to shoot.

As time went on, the populations of waterfowl decreased until their numbers became so few that many individuals realized that some types of controls would need to be imposed to preserve our wildlife. The outcome of this thinking was the passing of laws that limited the numbers and the length of time that a particular species could be hunted. With the coming of these restrictions market hunting became only a thing to reminisce about.

Wherever man has settled, wildlife in the area has been subjected to harassment. The previous paragraphs show some of the more intensive types of disturbances that occurred on Utah Lake. Concurrent with these activities and continuing into the present has been the harassment of wildlife just for "fun." This type of activity took many forms and usually occurred sporadically. The occasional disturbing of a nesting group of birds by someone invading their area, the potshot of a boy with rifle or shotgun, or any other act that would disturb the birds from carrying on their normal activities would fit into this category. These interruptions are by far the hardest to quantify because of their random nature, yet when accumulated over a given period of time, they are probably the most damaging to the birds. This type of activity is not only confined to the past but also occurs now. On several occasions during the summer of 1976, Brigham Young University personnel conducting research on the colonial nesting species at the lake found birds that had been shot and then left to rot on the ground below their nests.

Changes in Bird Populations

In addition to his direct influence on bird populations, man has affected bird habitats by changing the water level in the lake. There are two types of water level changes. One involves a yearly high period, usually in May or June, followed by a low period in September or October; the second type of fluctuation occurs over a period of years. The yearly fluctuation, unless it is very great, does not have too much effect on the habitat. Considerable change has been observed during the years of continued low water levels

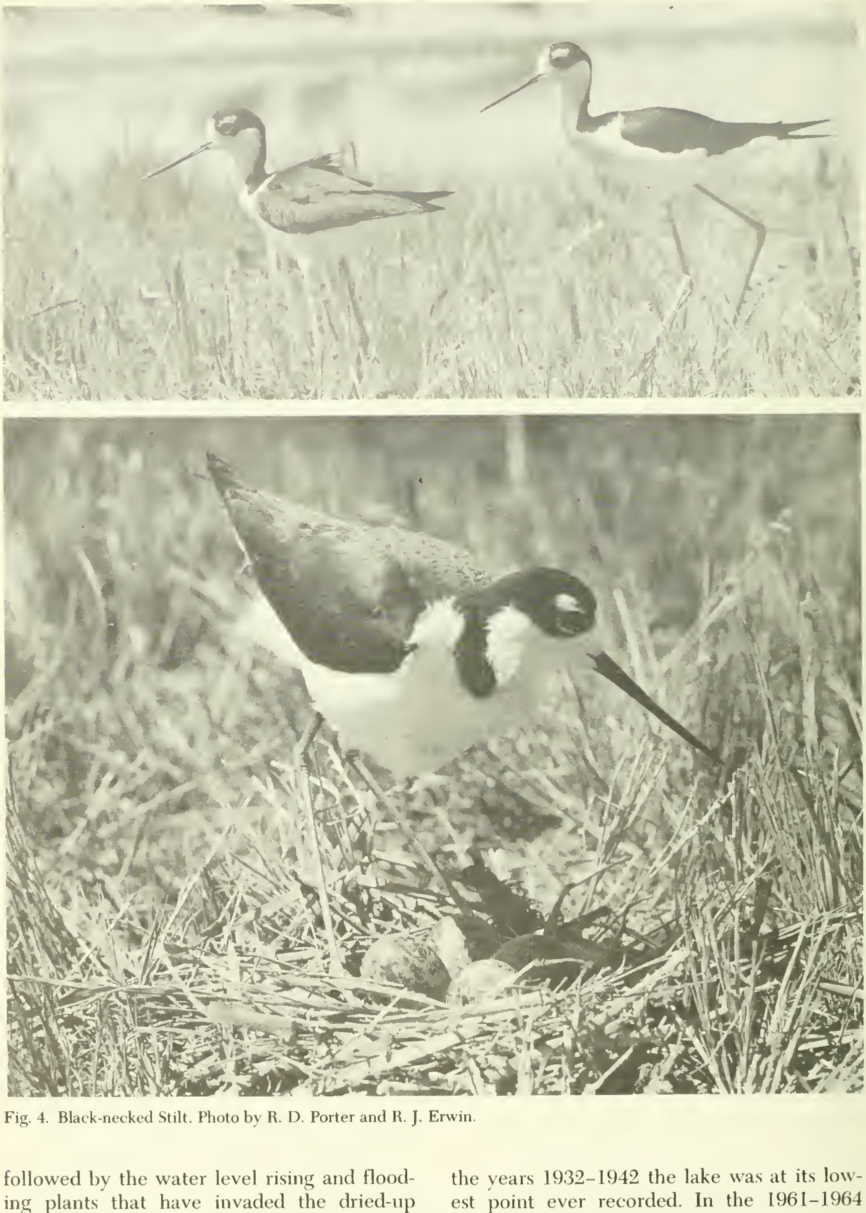

Fig. 4. Black-necked Stilt. Photo by R. D. Porter and R. J. Erwin.

followed by the water level rising and flooding plants that have invaded the dried-up areas. In the past 45 years (1931–1976) there have been two periods of low water. During the years 1932–1942 the lake was at its lowest point ever recorded. In the 1961–1964 period the lake level lowered again but not as much as in the earlier period.

In the mid 1930s Provo Bay was subjected to channelization. This resulted in the water being confined to narrow canals, with much of the area exposed. No attempt was made to maintain the channels or to install headgates to regulate the water flow because of protests by local conservation interests (*Evening Herald*, 15 April 1936:1,8). During this period farmers along the shore extended their grazing operations out into areas that 20 years before had been under water. Fence lines were extended out to contain the cattle, and considerable plant growth developed along the fence rows. In time the low-growing vegetation was replaced by willows and poplars, which attained considerable size. On the banks along the canals, poplar and willow trees became numerous. On the flat areas of Provo Bay and around Utah Lake brushy expanses of willow and tamarisk became established.

In the 1940s, as the level of the lake rose, the willows and tamarisk were first to be inundated. These partially submerged plants provided breeding habitat for Western Grebes, American Coot, Long-billed Marsh Wrens, Yellowthroats, Yellow-headed Blackbirds, Red-winged Blackbirds, and other species. Since the banks along the canals were higher as the result of the dredged materials, the willows and poplars were out of water and continued to grow into the 1950s and 1960s. As the trees matured into large, well-formed structures, they provided nesting habitat for the colonial Double-crested Cormorants and Great Blue Herons. In parts of Provo Bay the thickets of willow and tamarask also provided habitat for Snowy Egrets, Black-crowned Night Herons, and White-faced Ibis. Colonies of these three species became very extensive with the availability of protected nesting areas. Along the east side of Provo Bay, about a mile south of the mouth of Hobble Creek and about the same distance north, two fairly extensive rows of trees developed along existing fence rows. The trees along the north were used by Great Blue Herons until they fell or were blown over. Those along the south were not used extensively until the 1960s, when the trees at the western end (and in deeper water) were used by Double-crested Cormorants and those eastward in the row by Great Blue Herons. As the trees at the western end commenced to die, rot, and fall over, the cormorants nested more in the eastern part of the row and encroached on the herons. At the present time (1980) cormorants and herons are using the remaining trees together, with some herons moving about a half mile northward to a very tall stand of trees barely at the water's edge.

The status of the 200 species at the lake is not completely known. No doubt there is less nesting habitat around the lake now as compared to when the white man arrived in the valley in 1848. With a decrease in habitat and a great increase in use of the lake for recreation, there has probably been a decrease in number of birds that can utilize the lake and its environs for breeding, resting, and feeding. There is enough information at hand to discuss the population changes in about 20 species.

White Pelicans have used Utah Lake as a food source as far back as we have records. They once nested here, as has been mentioned, but no longer do so due to human harassment. They now nest on Gunnison Island in the Great Salt Lake and fly to Utah Lake for feeding and resting purposes only. The Double-crested Cormorant populations during the past 40 years have fluctuated considerably. Though numerous in the 1930s and 1940s, a decline occurred during the 1950s and 1960s. During the past decade there has been an increase in their numbers. Mitchell (1977) indicated that 54 percent of the known nesting colonies of cormorants in Utah occurred around Utah Lake. Great Blue Herons have been fairly numerous on a continuous basis around the lake. The location of their colonies has changed as they have been subjected to the influence of man. Early reports indicated that they nested in the bulrushes and a few nested in trees. Now, in the Utah Lake area, they nest almost exclusively in trees (see earlier reports). At Bear River Refuge, where their nesting habitat is protected, they still nest in the bulrushes. Harassment has probably been the major reason for the change in nesting habitat.

A comparatively new arrival in Utah and the Utah Lake area is the Cattle Egret. The

Fig. 5. Common Snipe. Photo by R. J. Erwin.

first record of the Cattle Egret at Utah Lake is 16 April 1971, when Hayward and Frost saw one in the wet meadow at the north Springville freeway exit (Hayward et al. 1976). From time to time since then one or more have been observed. During the summer of 1976, three pairs were seen and believed to have nested with a colony of Snowy Egrets south of the airport. Dennis Shirley, Utah State Division of Wildlife Resources, reported (pers. comm.) that in May 1980 about 25 Cattle Egrets nested with Snowy Egrets and Great Blue Herons in the same locality. For many years White-faced Ibis have been found around the lake where they feed in the wet meadows, but they were not known to breed here. In 1971 and 1972, Kaneko (1972) found a good-sized colony nesting in Provo Bay. They have been observed each year since then.

Henshaw (1875) considered the Bald Eagle to be a permanent breeding species around the lake. Now this species is found here primarily in winter, and then only occasionally is it seen. Most of the wintering population is located in the arid valleys west of Utah Lake. Porter et al. (1973) concluded that the decline of the Peregrine Falcon in Utah was due to a combination of climatic changes and pesticide contamination. The Ring-necked Pheasant was introduced into the fields around Utah Lake in 1922, when a pheasant farm was commenced by the Division of Wildlife Resources (Cottam 1929b). The Chukar, another introduction by the Division of Wildlife Resources, was first released in Utah in 1936 (Hayward et al. 1976). A few have been observed around the airport dike from time to time.

The Sandhill Crane formerly bred in suitable marsh habitat around the lake and was known to breed in this area as late as 1939 (Bee and Hutchings 1942). At the present time this crane is a migrant in the Utah Lake area. The Common Gallinule has been reported from around the lake several times. In May 1969 Hayward saw three at Powell's Slough, and, due to their continued presence over a period of time and to their courtship behavior, considered them to be breeding (Hayward et al. 1976). The Long-billed Curlew, although still present in small numbers, is not as plentiful as it was 40 or 50 years ago. This decrease is due primarily to the re-

duction of its breeding habitat by man's use of the land.

California Gull populations are probably higher now than in pioneer times. Human activities have provided a greater variety of food sources than was present formerly. Plowed fields are a good source of insects, cherries are used as a food supply (Cottam 1935), and the ever-present city dump and land fill operations are used by gulls as a food source. Breeding areas are adequate to sustain a large population. Cottam (1935) and Beck (1942b) reported great numbers using Rock Island as a breeding ground. As the water level went up and the available area on Rock Island became smaller, the gulls moved to the dikes in the cooling ponds at the United States Steel Plant at Geneva on the east side of the lake. Yearly, thousands of gulls nest on the dikes, where they are near all the food sources mentioned.

The Caspian Tern has not fared as well as the gulls. As long as there was an extensive land mass on Rock Island, gulls and terns were able to nest together there. As the land mass decreased in size, the terns were unable to compete with the gulls for nesting habitat, were preyed upon by the gulls, and so stopped nesting on the island. At the present time no colony of Caspian Terns is known to nest around the lake, although they still nest in the refuges around the Great Salt Lake.

A number of the small song birds are more common now than they were before the settlement of the valley. Pasture and hay fields have provided greater habitat for the Meadowlark. Plantings of trees and shrubs around homes and the development of city parks has increased the nesting habitat for the American Robin, Black-headed Grosbeak, and House Finch. Barns, outbuildings, and bridges are used extensively by Barn and Cliff Swallows for nesting purposes. Henshaw (1875:2) specifically mentioned the Robin as being more abundant than when the settlers first arrived.

The Blue Grosbeak is more common around the lake than formerly. Several have been observed in the vicinity of the lake over the past 15 years. This species is found more commonly in the southern and eastern parts of Utah. Two introduced species, the House Sparrow and Starling, are now common residents of the lake environs. Sparrows were introduced into many parts of the United States and were reported in Utah prior to 1870 (Hayward et al. 1976). The Starling is a more recent arrival, first reported in the Utah Lake area during the winter of 1951–1952 (Behle 1954). Both species are very adaptable and have, in some instances, replaced the native bird fauna. Formerly the Common Crow was a sparse breeder around the lake. Bee and Hutchings (1942) and Richards and White (1963) reported a nest at the mouth of Hobble Creek in the month of May. Richards (1971) indicated that the eastern race *Corvus brachyrhynchos brachyrhynchos* is the subspecies found in the valley. At the present time the crow is a winter visitant, being found here from November through February and March.

Early Reports on Avian Species (1872–1905)

As mentioned previously, the first recorded white men to observe bird life around Utah Lake were Dominguez and Velez de Escalante and their associates in 1776. During the next 100 years we know very little about bird life around the lake except for scattered statements in some of the pioneer diaries. In 1872, H. W. Henshaw and H. C. Yarrow accompanied a geographical survey party that spent some time in Utah Valley in July and November and December.

Henshaw (1875), in describing some of the ducks they saw and collected at Utah Lake, indicated that they were plentiful. He reported that

> [italics added] the borders of Utah Lake afford a home in summer for *very many* of these ducks [Gadwall, p. 447].

In writing about the Cinnamon Teal, which he called the "Red-breasted Teal," he wrote

> In Utah, I learned from good authority that it breeds in *great numbers*, especially in the marshes of Utah Lake [p. 478].

He wrote about the Greater Blackhead [Greater Scaup]

> Among the *hordes of ducks* seen at Utah Lake in November, the presence of this species was recognized and several were shot [p. 479],

Fig. 6. Black Tern. Photo by R. J. Erwin.

and the Goldeneye

> visits the neighborhood of Utah Lake in *great abundance* during the fall, and is, I think, a winter resident [p. 480].

The Red-breasted Merganser he considered

> *rather common* at Utah Lake in November, more so than either of its congeners [Hooded or Common Mergansers, p. 484].

The American Wigeon

> occurs in *great abundance* on Utah Lake during the fall, where it is found in considerable numbers even late in November, and, indeed, in the neighborhood of certain warm springs and sloughs about Provo, more or less may find sufficient inducement to keep them all winter [p. 475].

Besides the ducks, Henshaw (1875) mentioned the presence of a number of other species, which gives us a better picture of the bird life around the lake over 100 years ago. His statements are as follows:

Common Loon [called by Henshaw the Great Norther Diver]

> was said by fishermen of Utah Lake to be *rather common*, remaining in their waters till quite late in the fall [p. 488].

Western Grebe

> is a *common species* of Utah Lake in summer perhaps the most so of the family; and breeds here [p. 466].

White Pelicans [American Pelican]

> were seen at Utah Lake in July *sparingly* [p. 485].

Great Blue Heron was seen

> on the borders of Utah Lake as late as December, and it probably remains there through the winter [p. 464].

Fig. 7. Spotted Sandpiper. Photo by R. D. Porter.

Black-crowned Night Heron [Night Heron]

appears to *occur commonly* in Utah about the large lakes and marshes. As it was seen about Utah Lake in December, it probably is a resident [p. 466].

White-faced Ibis [Glossy Ibis]

is well known to the gunners about Utah Lake under the name of "Black Snipe." It is said to be *common* in spring and fall, and may, I think, breed in this vicinity [p. 463]

Rough-legged Hawk [Black Hawk]:

None were obtained until we reached Provo, where it was the most numerous of the hawks. Utah Lake and the surrounding marshes attract *multitudes of waterfowl*; and this undoubtedly explains in part the abundance of hawks at this season, since wounded and disabled ducks must form no inconsiderable part of their food [p. 426].

Bald Eagle [White-headed Eagle]

is *numerous* in Utah, perhaps more so than is usual in the West, as the presence of several large lakes well stocked with fish attract it. It regularly visits the shores of Utah Lake from the adjoining mountains, where it finds opportunities for rearing its young undisturbed, within easy reach of the lake [p. 427].

Marsh Hawk was

near Utah Lake, their *numbers were scarcely less* than were the Rough-legged Hawks [p. 416].

Ring-billed Gull

is *common* on the larger bodies of water throughout Utah. Numbers were seen on the Provo River late in November, when the lake was frozen over. They are without doubt winter residents here [p. 485].

Forster's Tern [Howell's Tern]

was *quite common* at Utah Lake in the summer, where it breeds along the shores [p. 486].

Long-billed Marsh Wren:

In the extensive marshes which border Utah Lake, and which are covered with a dense growth of coarse grasses and reeds, these wrens were *exceedingly numerous*; and, in breaking a path through the reeds, which often are so dense as to render progress well nigh impossible, *hundreds* of these little birds were startled up from their retreats, while their harsh notes were heard on all sides in expostulation. Almost as numerous as the birds themselves were their nests, which were seen on all sides, suspended on the tall, waving stems [p. 186].

Robin:

At Provo, it was *very common*, where a few years since it was unknown; the advent of this, as of several other well known birds, following the occupation of the soil and its subsequent tillage by the settlers [p. 143].

Tree Sparrow:

The species was found *common* at Provo in December [p. 277].

Bobolink:

is a *rather common* bird in the fields about Provo, Utah, where the parent birds were noticed feeding their young July 25 [p. 311].

Common Crow

met with only at Provo, where a number were seen at different times. Said by the settlers to have appeared within a few years [p. 327].

During the next 30 years there is a paucity of information concerning the bird life of Utah Lake. In 1892, H. C. Johnson, a resident of American Fork and an interested oologist, collected eggs of the following species of birds in Powell's Slough: Bittern, Blue-winged Teal, Snipe, Sora Rail, Coot, Long-billed Marsh Wren, and Yellow-headed Blackbird. The following year Johnson (1893) reported seeing a loon on the lake and collected eggs of the Bittern, Mallard, Wilson Snipe, Coot, Long-billed Marsh Wren, and Yellow-headed Blackbird. He also observed Great Blue Herons nesting in Springville Lake (Provo Bay) and stated that they were on an island which was

simply covered with Great Blue Herons and we counted about 60 nests built flat on the tules (there being no trees in that part of the country).

He found in the same locality nests of the Western and Eared Grebes.

A decade later the Rev. S. H. Goodwin (1904) of Provo visited Rock Island in Utah Lake and reported that a colony of White Pelicans was nesting there. He estimated there were about 200 young on the island. He noted that California Gulls and Forster's Terns were residents of the island along with the pelicans.

About the same time that the Rev. Goodwin had visited Rock Island, A. O. Treganza of Salt Lake City visited a Western Grebe colony on Utah Lake. He collected a set of eggs that eventually became part of the egg collection of E. J. Court of Washington, D.C. Court loaned this set of eggs to Dr. R. W. Shufeldt, who was making a study of the eggs of loons and grebes. In 1914 Dr. Shufeldt published his findings and reported on the Western Grebe eggs collected by Tregenza:

The colony of grebes, where these eggs were collected, was located about two miles from the shore, and contained about one hundred nests. Some of the clutches were in advanced incubation.

The eggs were collected on 29 May 1904.

Recent Reports on Avian Species (1905–present)

Cottam (1927), in an annotated list, mentioned a number of species in and around the lake. The published account of his thesis

(Cottam 1929c) listed 72 water birds known to occur in Utah County. He regarded 29 as breeding birds, 33 as occurring in the winter, 39 as common migrants, and 15 as residents. These lists were based on his field work, collected specimens, and from the literature.

During this same period of time Cottam participated with the National Audobon Society in their annual Christmas census of birds. The results (Cottam 1928, 1929a) showed that in 1928 his party saw 51 species and 1971 individuals and in 1929 they saw 59 species and 2588 individuals. Both surveys were in the lake area.

Commencing in the 1930s and contining to the present, much has been written concerning the avifauna of the lake. Unfortunately this material is scattered in many publications, where sometimes it is incidental to the main theme of the publication. Some material (field notes and observations) has been collected but has not been published. The following brief summary of the literature from 1930 to the present will be given. For convenience it has been arranged into three categories: (1) Papers and reports published in nationally recognized journals and periodicals, (2) those found in periodicals of local interest and distribution, and (3) unpublished data.

Two short notes by Allen (1936, 1937) indicate several species nested on the lake and state that pelicans were still being shot indiscriminately. C. Lynn Hayward served as a warden for the National Audubon Society in 1936 (personal interview) and Reed Fautin, then a graduate student at Brigham Young University, carried on the warden patrol of pelicans, avocets, and long-billed curlews in 1937 (Allen 1937). Beck (1942a,b, 1943, 1947) added considerable information to the status of gulls on the lake. His 1942a paper indicated that six species of gulls frequented the lake, and the 1942b publication gave detailed observations of the breeding ecology of the California Gull on Rock Island. He estimated the 1942 postnesting population of gulls to be 68,744. His third paper described the plumage changes that occur in California Gulls from hatching to maturity. The 1947 report was a popular account of the 1942b publication on the breeding biology of the gulls (1942).

Bee and Hutchings (1942) listed 47 species as nesting around the lake. Behle (1942, 1945, 1966) specifically mentioned a number of birds at Utah Lake. The 1942 and 1966 papers listed one species each from the lake (Sanderling and Wood Duck). The 1945 publication listed 13 species seen at Rock Island in 1932 and indicated that 6 species were nesting on the island at that time. Cottam (1941) reported collecting a LeConte's Sparrow near Utah Lake in December 1927 for the only collected specimen known for the state of Utah. During the spring and summer of 1937 Fautin (1940, 1941a,b) carefully studied two colonies of Yellow-headed Blackbirds near the mouth of Provo River. His report gives a good ecological picture of this species at Utah Lake.

Hayward (1935a,b, 1936, 1937, 1944, 1966) contributed a number of studies on the status of birds at Utah Lake. The 1935a paper gave information on the Caspian Tern for a six-year period (1927–1933) on Rock Island. His second paper compares bird life in Bear Lake and Utah valleys and mentions a few water birds at Utah Lake. The 1936 publication gives observations on 14 species of shore birds seen during the summer of 1936 at the lake. The remaining papers report the presence of isolated species at the lake.

Hayward, Cottam, Woodbury, and Frost (1976) contributed considerable information concerning the species found on and around the lake.

Johnson (1935a,b) reported collecting two Snow Buntings near the mouth of Provo River. Kingery (1974, 1976) recorded the Common Tern around the lake in April 1974 and June 1976. Lockerbie (1947) sighted two Brown Pelicans in a flock of White Pelicans on Utah Lake in April 1947. Mitchell (1975) reviewed the status of the Double-crested Cormorant in Utah and gave data on the colonies around Utah Lake. Mitchell (1977) reported a study of the breeding biology of the Utah Lake Cormorants. Scott (1968) reported a Red Knot at Utah Lake 11 May 1968, the only report of this species for the lake. Webb's Christmas bird counts for the Audubon Society (1973b, 1974b, 1975a, 1976, 1977b, 1978c, 1979b) mentioned a number of species of water birds found at the lake dur-

ing the seven years mentioned. Four rare species reported at Utah Lake by Kingery (1977) were the Red-necked Grebe, White-winged Scoter, Sabine's Gull, and Common Grackle. Migrant species (Franklin Gull, Blue-gray Gnatcatcher, and Orange-crowned Warbler) lingering at Utah Lake into December 1977 were recorded by Kingery (1978).

Among the publications of local interest and distribution are publications by the Division of Wildlife Resource, Utah Audubon Society, and Mount Timpanogos Audubon Chapter of the National Audubon Society. Jensen (1974), in a section that deals with Utah County, gives information on land ownership and vegetative cover in the Provo and Goshen Bay areas of Utah Lake and also the hunter use and numbers of geese and ducks hunted in the county.

The Utah Audubon Society, with headquarters in Salt Lake City, has published for many years the *Utah Audubon News*. From 8 to 12 numbers have appeared each year, and many of the issues contain references to birds around Utah Lake. For a number of years annual field trips by the society were taken to many areas in the state. One of these annual trips was to Utah Lake and was reported in the Utah Audubon News. The number of individual birds seen, as well as the different species observed, was recorded and gives a picture of the bird life around the lake. Cassal (1966), Ferris (1965), Geoghagen (1965), Kashin (1957, 1959, 1960, 1961, 1962, 1963, 1964), Lockerbie (1955a,b), Lockerbie and Behle (1952), Stone (1968), Tainter (1956), and Weissman (1968) published information on Utah Lake bird life. From these reports we know that a Great Blue Heron colony existed in the north part of the lake from at least 1955 to 1962, since it is mentioned a number of times during this time period. The earliest is Lockerbie (1955a), who reported 21 herons standing in their nests in the spring of 1955. Kashin (1960) reported two Great Blue Heron colonies with a total of 50 nests.

The Mount Timpanogos Chapter of the National Audubon Society, at Provo, Utah, has published since late in 1972 the *Timpanogos Honker*, which has contained articles dealing with birds at the lake. Simmons (1974) reported the presence of a Cattle Egret at the lake in April 1974. Webb (1973a, 1974a, 1975b, 1977a, 1978a, 1979a, 1980) reported the results of several local Christmas bird counts with, in some instances, more information than appeared in the American bird accounts. Webb (1977c) observed a Mockingbird late in October 1977 at the lake. In December of the same year he (1978b) saw five species of shorebirds that normally migrate earlier in the season. Two anonymous reports (1978a,b) and short notes by Johnson and Webb (1977) and Monroe (1979) listed common species observed at the lake during field trips taken by the Mount Timpanogos Chapter of the Audubon Society.

Three sources of unpublished information on Utah Lake that contain valuable information are field notes, master's theses, and data cards on the egg collections in Monte L. Bean Life Science Museum at Brigham Young University. The field notes of R. G. Bee (1924–1962), C. L. Hayward (early 1930s–present), and H. H. Frost (1960–present) contain valuable notes on birds and some of the bird colonies around the lake.

A number of master's theses deposited at Brigham Young University give further information on the bird life of the lake. Cottam's thesis (1927) was cited above. Murphy (1951) studied the birds wintering along the east shore of the lake south of the mouth of Provo River and adjacent to the Provo Airport (October 1950–March 1951) and reported 24 species of passerine birds wintering in the area, including 21 winter visitants, 8 permanent residents, 4 summer residents, and 2 migrants. Talley (1957) studied the nasal mites of overwintering Red-winged Blackbirds and Brewer's Blackbirds found along the north shore of Provo Bay. Barnett (1964) studied the waterfowl nesting at Powell's Slough and found only 6 species. He concluded that lack of good marsh habitat, fluctuating water levels, and cattle and predator destruction of the nests were limiting factors in waterfowl production. He also listed the seasonal distribution of 26 other species that frequented the marsh. Kaneko (1972) reported the nesting of White-faced Ibis in the Provo Bay area. This was followed by Mitchell's

Fig. 8. Wilson's Phalarope. Photo by R. J. Erwin.

(1974) study on the Double-crested Cormorant in the Provo Bay area and at Geneva Dike and Gunnell's (1976) study of the Snowy Egret in the same two localities. Isham (1975) discussed the spacial distribution of the nests of the Black-crowned Night Heron and the Snowy Egret and obtained some of his data from the colonies in Provo Bay and at the Geneva Dike. Alford (1978) obtained some prenesting behavior data from a colony of White-faced Ibis located in the Provo Bay area of Utah Lake.

Earlier in this century bird egg collecting was a popular avocation. Some of these collections were very well prepared and, in addition to the eggs themselves, data were kept with each set of eggs indicating the date collected, general location, specific nesting habitat and, frequently, the nesting materials, and other bird species nesting in the same locality. BYU's Monte L. Bean Life Science Museum has a number of collections made by individuals in Utah that specifically designate Utah Lake as the collecting locale. This information is very valuable in giving us a picture of some of the nesting birds around the lake (see Table 2).

Bird Populations at Utah Lake

In summarizing the information found in the printed reports and the unpublished data, an understanding of the avifauna of Utah Lake emerges. Two hundred species of birds have been reported from the lake and its surroundings, representing 46 families (Table 2). Table 3 indicates the relative abundance of these species.

The habitats around the lake have been placed into five groups. Many of the 200 species are not restricted to a single habitat but may be found in two or more areas. Table 4 shows the habitat preferences of the birds at the lake.

TABLE 2. Birds of Utah Lake, their relative abundance, seasonal occurrence, and habitat preferences.

Abundance

A	Abundant—Will usually be seen	(75–100 percent of time)
C	Common—May not be seen each time in the field	(25–75 percent of time)
U	Uncommon—Will only be seen occasionally	(10–25 percent of time)
Ca	Casual—Only seen once in great while	(less than 10 percent)
R	Rare—Reported only once or a very few times	(less than 1 percent)

Seasonal Occurrence

M	Migrant	SR+	Summer resident, a few wintering
M+	Migrant, occasionally remaining in area	WV	Winter visitant
PR	Permanent resident	Jan	Month or season when only seen once
SR	Summer resident		

*Breeding **Introduced

Name	Abundance	Seasonal occurrence	Habitats: Open water	Marshy land	Beaches	Wet meadow	Dry meadow
Family Gaviidae							
Common Loon *Gavia immer*	C	M	X				
Family Podicipedidae							
Red-necked Grebe *Podiceps grisegena*	R	May	X	X			
Horned Grebe *Podiceps auritus*	Ca	M	X	X			
*Eared Grebe *Podiceps nigricollis californicus*	A	SR+	X	X			
**Western Grebe *Aechmophorus occidentalis*	A	SR+	X	X			
*Pied-billed Grebe *Podilymbus podiceps podiceps*	C	PR	X	X			
Family Pelecanidae							
*White Pelican *Pelecanus erythrorhynchos*	C	SR	X	X			
Brown Pelican *Pelecanus occidentalis*	R	Apr	X	X			
Family Phalacrocoracidae							
*Double-crested Cormorant *Phalacrocorax auritus*	C	SR+	X	X			
Family Ardeidae							
*Great Blue Heron *Ardea herodias treganzai*	A–C	SR+	X	X	X		
*Cattle Egret *Bubulcus ibis ibis*	Ca	SR	X	X	X		
Common Egret *Casmerodius albus egretta*	R	Summer	X	X	X		
*Snowy Egret *Egretta thula brewsteri*	C	SR	X	X	X	X	

Table 2 continued.

Name	Abundance	Seasonal occurrence	Habitats: Open water	Marshy land	Beaches	Wet meadow	Dry meadow
°Black-crowned Night Heron *Nycticorax nyxticorax hoactli*	C	SR+	X	X			
°American Bittern *Botaurus lentiginosus*	U	SR+		X			
Family Ciconiidae							
Wood Stork *Mycteria americana*	R	Summer		X			
Family Threskiornithidae							
°White-faced Ibis *Plegadis chihi*	C	SR+		X		X	
Family Anatidae							
Whistling Swan *Olor columbianus*	Ca	WV	X	X			
°Canada Goose *Branta canadensis*	C	SR+	X	X		X	
White-fronted Goose *Answer albifrons*	R	Apr & Nov	X	X			
Snow Goose *Chen caerulescens caerulescens*	U	M	X	X			
°Mallard *Anas platyrhynchos platyrhynchos*	C	PR	X	X			
Black Duck *Anas rubripes*	R	WV	X	X			
°Gadwall *Anas strepera*	C	PR	X	X			
°Pintail *Anas acuta*	C	PR	X	X			
°Green-winged Teal *Anas crecca carolinensis*	C	PR	X	X			
°Blue-winged Teal *Anas discors discors*	C-U	PR	X	X			
°Cinnamon Teal *Anas cyanoptera septentrionalium*	C	SR+	X	X			
American Wigeon *Anas americana*	U	SR+	X	X			
°Northern Shoveler *Anas clypeata*	C	SR+	X	X			
Wood Duck *Aix sponsa*	R	Nov	X	X			
°Redhead *Aythya americana*	C	SR+	X	X			

Table 2 continued.

Name	Abundance	Seasonal occurrence	Habitats: Open water	Marshy land	Beaches	Wet meadow	Dry meadow
Ring-necked Duck *Aythya collaris*	Ca	WV	X	X			
Canvasback *Aythya valisineria*	C	SR+	X	X			
Greater Scaup *Aythya marila nearctica*	Ca	M	X	X			
Lesser Scaup *Aythya affinis*	C	M	X	X			
Common Goldeneye *Bucephala clangula americana*	C	WV	X	X			
Barrow's Goldeneye *Bucephala islandica*	Ca	WV	X	X			
Bufflehead *Bucephala albeola*	C–U	WV	X	X			
Oldsquaw *Clangala hyemalis*	Ca	M	X	X			
White-winged Scoter *Melanitta deglandi deglandi*	R	Apr	X	X			
°Ruddy Duck *Oxyura jamaicensis*	C	SR+	X	X			
Hooded Merganser *Mergus cucullatus*	U	WV	X	X			
Common Merganser *Mergus merganser americanus*	U	WV	X	X			
Red-breasted Merganser *Mergus serrator serrator*	C	PR	X	X			
Family Cathartidae Turkey Vulture *Cathartes aura teter*	U	SR				X	X
Family Accipitridae Sharp-shinned Hawk *Accipiter striatus velox*	Ca	PR				X	X
Cooper's Hawk *Accipiter cooperii*	Ca	SR				X	X
Red-tailed Hawk *Buteo jamaicensis*	U	PR				X	X
Swainson's Hawk *Buteo swainsoni*	U	PR				X	X
Rough-legged Hawk *Buteo lagopus sanctijohannis*	U	WV				X	X

Table 2 continued.

Name	Abundance	Seasonal occurrence	Open water	Marshy land	Beaches	Wet meadow	Dry meadow
			Habitats				
Ferruginous Hawk *Buteo regalis*	U	SR+				X	X
Golden Eagle *Aquila chrysaetos*	U	PR				X	X
Bald Eagle *Haliaeetus leucocephalus*	U	WV				X	X
°Marsh Hawk *Circus cyaneus hudsonius*	C	PR		X		X	X
Family Pandionidae							
Osprey *Pandion haliaetus carolinensis*	Ca	M	X	X		X	
Family Faconidae							
Prairie Falcon *Falco mexicanus*	Ca	PR		X		X	X
Peregrine Falcon *Falco peregrinus*	Ca	PR		X		X	X
Merlin *Falco columbarius*	Ca	PR		X		X	X
American Kestrel *Falco sparverius sparverius*	C	PR		X		X	X
Family Phasianidae							
°° °Ring-necked Pheasant *Phasianus colchicus*	C	PR		X		X	X
°°Chukar *Alectoris chukar*	C	PR		X		X	X
Family Gruidae							
°Sandhill Crane *Grus canadensis*	U	M		X		X	X
Family Rallidae							
°Virginia Rail *Rallus limicola limicola*	U	PR		X			
°Sora *Porzana carolina*	U	PR		X			
°?Common Gallinule *Gallinula chloropus cachinnaus*	Ca	SR		X			
°American Coot *Fulica americana americana*	A	SR+	X	X	X	X	
Family Charadriidae							
Semipalmated Plover *Charadrius semipalmatus*	Ca	M		X	X	X	

Table 2 continued.

Name	Abundance	Seasonal occurrence	Habitats: Open water	Marshy land	Beaches	Wet meadow	Dry meadow
°Snowy Plover *Charadrius alexandrinus nivosus*	U	SR		X	X	X	
°Killdeer *Charadrius vociferus vociferus*	C	PR		X	X	X	X
Black-bellied Plover *Pluvialis squatarola*	U	M		X	X	X	
Family Scolopacidae							
°Common Snipe *Cappella gallinago delicata*	C	PR			X	X	X
°Long-billed Curlew *Numenius americanus*	U	SR+			X	X	X
°Spotted Sandpiper *Tringa macularia*	C	SR		X	X	X	
Solitary Sandpiper *Tringa solitaria*	U	M+		X	X	X	
Greater Yellowlegs *Tringa melanoleuca*	C	M+		X	X	X	
Lesser Yellowlegs *Tringa flavipes*	C	M+		X	X	X	
°Willet *Catoptrophorus semipalmatus inornatus*	C–U	SR		X	X	X	
Red Knot *Calidris canutus rufa*	R	May		X	X	X	
Baird's Sandpiper *Calidris bairdi*	Ca	M		X	X	X	
Least Sandpiper *Calidris minutilla*	U	M+		X	X	X	
Dunlin *Calidris alpina pacifica*	U	M		X	X	X	
Semipalmated Sandpiper *Calidris pusilla*	Ca	M		X	X	X	
Western Sandpiper *Calidris mauri*	U	M		X	X	X	
Sanderling *Calidris alba*	U	M		X	X	X	
Long-billed Dowitcher *Limnodromus scolopaceus*	C	M+		X	X	X	
Marbled Godwit *Limosa fedoa*	C	M+		X	X	X	

Table 2 continued.

Name	Abundance	Seasonal occurrence	Habitats: Open water	Marshy land	Beaches	Wet meadow	Dry meadow
Family Recurvirostridae							
°American Avocet *Recurvirostra americana*	C	SR+	X	X	X	X	
°Black-necked Stilt *Himantopus mexicanus mexicanus*	C	SR	X	X	X	X	
Family Phalaropodidae							
°Wilson's Phalarope *Phalaropus tricolor*	C	SR	X	X	X	X	
Northern Phalarope *Phalaropus lobatus*	C	M	X	X	X	X	
Family Laridae							
Glaucous Gull *Larus hyperboreus hyperboreus*	R	M	X		X		
Herring Gull *Larus argentatus smithsonianus*	R	Feb	X				
°California Gull *Larus californicus*	A	SR+	X	X	X	X	X
Ring-billed Gull *Larus delawarensis*	A	WV	X	X	X	X	X
Franklin's Gull *Larus pipixcan*	Ca	SR	X	X	X		
Bonaparte's Gull *Larus philadelphia*	Ca	M	X	X	X		
Sabine's Gull *Xema sabini sabini*	Ca	Apr	X	X	X		
°Forster's Tern *Sterna forsteri*	C	SR	X	X	X		
Common Tern *Sterna hirundo*	Ca	M	X	X	X		
°Caspian Tern *Sterna caspia*	U	SR	X	X	X		
°Black Tern *Chlidonias niger surinamensis*	C	SR	X	X	X		
Family Columbidae							
°Mourning Dove *Zenaida macroura marginella*	C	SR+					X
Family Stigidae							
Screech Owl *Otus asio*	Ca	PR				X	X
Great Horned Owl *Bubo virginianus*	Ca	PR				X	X

Table 2 continued.

Name	Abundance	Seasonal occurrence	Habitats: Open water	Marshy land	Beaches	Wet meadow	Dry meadow
Burrowing Owl *Athene cunicularia hypugaea*	Ca	SR +					X
°Long-eared Owl *Asio otus tuftsi*	C	PR				X	X
°Short-eared Owl *Asio flammeus flammeus*	C	PR				X	X
Family Caprimulgidae							
°Common Nighthawk *Choredeiles minor*	C	SR		X		X	X
Family Apodidae							
Black Swift *Cypseloides niger borealis*	R	May					X
Chimney Swift *Chaetura pelagica*	R	May					X
Vaux's Swift *Chaetura vauxi vauxi*	Ca	M					X
White-throated Swift *Aeronautes saxatalis*	U	M					X
Family Trochilidae							
Broad-tailed Hummingbird *Selasphorus platycercus platycercus*	U	SR				X	X
Family Alcedinidae							
Belted Kingfisher *Megaceryle alcyon caurina*	Ca	PR	X				
Family Picidae							
°Common Flicker *Colaptes auratus*	C	PR				X	X
Lewis' Woodpecker *Asyndesmus lewis*	Ca	M				X	X
Hairy Woodpecker *Dendrocopos villosus*	U	PR				X	X
Downy Woodpecker *Dendrocopos pubesceus leucurus*	U	PR				X	X
Family Tyrannidae							
°Eastern Kingbird *Tyrannus tyrannus*	C	SR				X	X
Western Kingbird *Tyrannus verticalis*	C	SR				X	X
°Say's Phoebe *Sayornis saya*	U	SR				X	X
°Willow Flycatcher *Empidonax trailli*	C	SR				X	X

Table 2 continued.

Name	Abundance	Seasonal occurrence	Habitats: Open water	Marshy land	Beaches	Wet meadow	Dry meadow
Gray Flycatcher *Empidonax wrightii*	Ca	SR				X	X
Western Wood Pewee *Contopus sordidulus*	Ca	SR				X	X
Family Alaudidae							
Horned Lark *Eremophila alpestris*	Ca	PR					X
Family Hirundinidae							
Violet-green Swallow *Tachycineta thalassina lepida*	C	SR	X	X		X	X
Tree Swallow *Tachycineta bicolar*	C	SR	X	X		X	X
Purple Martin *Progne subis*	Ca	M				X	X
°Rough-winged Swallow *Stelgidopteryx ruficollis*	C	SR	X	X		X	X
°Bank Swallow *Riparia riparia riparia*	C	SR	X	X		X	X
°Barn Swallow *Hirundo rustica erythrogaster*	C	SR	X	X		X	X
Cliff Swallow *Petrochelidon pyrrhonota*	C	SR	X	X		X	X
Family Motacillidae							
Water Pipit *Anthus spinoletta*	C	WV		X	X	X	
Family Laniidae							
Loggerhead Shrike *Lanius ludovicianus*	C	SR+				X	X
Northern Shrike *Lanius excubitor invictus*	Ca	WV				X	X
Family Cinclidae							
Dipper *Cinclus mexicanus unicolor*	Ca	PR	X				
Family Troglodytidae							
Rock Wren *Salpinctes obsoletus obsoletus*	R	PR					X
°Long-billed Marsh Wren *Cistothorus palustris*	C	PR		X			
House Wren *Troglodytes aedon parkmanii*	Ca	SR				X	X

Table 2 continued.

Name	Abundance	Seasonal occurrence	Habitats: Open water	Marshy land	Beaches	Wet meadow	Dry meadow
Family Mimidae							
Mockingbird *Mimus polyglottos leucopterus*	Ca	SR					X
Sage Thrasher *Oreoscoptes montanus*	R	SR					X
Family Muscicapidae							
Mountain Bluebird *Sialia currucoides*	Ca	M				X	X
Townsend's Solitaire *Myadestes townsendi townsendi*	U	M				X	X
Swainson's Thrush *Catharus ustulatus*	Ca	M					X
Hermit Thrush *Catharus guttatus*	Ca	M					X
°American Robin *Turdus migratorius propinquus*	C	PR				X	X
Blue-gray Gnatcatcher *Polioptila caerulea amoenissima*	U	SR				X	X
Family Sylviidae							
Ruby-crowned Kinglet *Regulus calendula cineraceus*	Ca	PR					X
Family Paridae							
Black-capped Chickadee *Parus atricapillus*	C	WV				X	X
Family Emberizidae							
Snow bunting *Plectrophenax nivalis nivalis*	U	WV				X	X
°Song Sparrow *Zonotrichia melodia*	C	PR		X		X	X
Lincoln's Sparrow *Zonotrichia lincolnii*	Ca	M				X	X
White-crowned Sparrow *Zonotrichia leucophrys*	C	WV				X	X
Dark-eyed Junco *Junco hyemalis*	C	WV		X		X	X
Savannah Sparrow *Ammodramus sandwichensis*	C	SR				X	X
Le Conte's Sparrow *Ammodramus leconteii*	R	Dec				X	X
Tree Sparrow *Spizella arborea ochracae*	C	WV				X	X

Table 2 continued.

Name	Abundance	Seasonal occurrence	Habitats: Open water	Marshy land	Beaches	Wet meadow	Dry meadow
Chipping Sparrow *Spizella passerina arizonae*	Ca	M				X	X
Vesper Sparrow *Pooecetes gramineus*	U	SR				X	X
Lark Sparrow *Chondrestes grammacus strigatus*	Ca	SR				X	X
Sage Sparrow *Aimophila belli nevadensis*	U	SR				X	X
Green-tailed Towhee *Pipilo chlorurus*	U	SR				X	X
Rufous-sided Towhee *Pipilo erythrophthalmus*	Ca	PR				X	X
Black-headed Grosbeak *Pheucticus melanocephalus melanocephalus*	Ca	SR				X	X
Blue Grosbeak *Passerina caerulea interfusa*	U	SR				X	X
Lazuli Bunting *Passerina amoena*	Ca	SR				X	X
Western Tanager *Piranga ludoviciana*	U	M				X	X
Family Parulidae							
Orange-crowned Warbler *Vermivora celata*	U	SR				X	X
Nashville Warbler *Vermivora ruficapilla ridgwayi*	Ca	M				X	X
Virginia's Warbler *Vermivora virginiae*	Ca	SR				X	X
°Yellow Warbler *Dendroica petechia*	C	SR				X	X
Black-throated Gray Warbler *Dendroica nigrescens nigrescens*	Ca	SR				X	X
Townsend's Warbler *Dendroica townsendi*	U	SR				X	X
Yellow-rumped Warbler *Dendroica coronata*	C	M				X	X
°Common Yellowthroat *Geothlypis trichas*	C	SR				X	X
MacGillivray's Warbler *Geothlypis tolmiei*	Ca	M				X	X

Table 2 continued.

Name	Abundance	Seasonal occurrence	Habitats: Open water	Marshy land	Beaches	Wet meadow	Dry meadow
Wilson's Warbler *Wilsonia pusilla*	Ca	M				X	X
Family Vireonidae							
Solitary Vireo *Vireo solitarius*	R	May				X	X
Warbling Vireo *Vireo gilvus*	R	May				X	X
Family Icteridae							
Northern Oriole *Icterus galbula*	C	SR					X
°Yellow-headed Blackbird *Xanthocephalus xanthocephalus*	C	SR+		X		X	X
°Red-winged Blackbird *Agelaius phoeniceus*	C	PR				X	X
°Western Meadowlark *Sturnella neglecta*	C	PR				X	X
Common Grackle *Quiscalus quiscula*	R	Mar				X	X
°Brewer's Blackbird *Euphagus cyanocephalus*	C	PR				X	X
°Brown-headed Cowbird *Molothrus ater*	C	SR		X		X	X
°Bobolink *Dolichonyx oryzivorus*	U	SR				X	X
Family Fringillidae							
Pine Siskin *Carduelis pinus pinus*	C	WV				X	X
°American Goldfinch *Carduelis tristis pallida*	C	PR				X	X
Cassin's Finch *Carpodacus cassinii*	Ca	SR				X	X
House Finch *Carpodacus mexicanus frontalis*	Ca	PR				X	X
Evening Grosbeak *Coccothraustes vespertinus brooksi*	Ca	M				X	X
Family Ploceidae							
°° °House Sparrow *Passer domesticus domesticus*	A	PR				X	X
Family Sturnidae							
°° °Starling *Sturnis vulgaris vulgaris*	A	PR				X	X

Table 2 continued.

Name	Abundance	Seasonal occurrence	Habitats: Open water	Marshy land	Beaches	Wet meadow	Dry meadow
Family Corvidae							
Pinon Jay *Gymnorhinus cyanocephala*	Ca	M				X	X
Scrub Jay *Aphelocoma coerulescens*	Ca	M				X	X
°Black-billed Magpie *Pica pica hudsonia*	A	PR				X	X
Common Crow *Corvus brachyrhynchos*	A	WV	on ice			X	X
Raven *Corvus corax sinuatus*	U	PR				X	X

The seasonal occurrence of the birds has been categorized into seven groups: (1) migrants, (2) migrants occasionally remaining in the area, (3) permanent residents, (4) summer residents, (5) summer residents that may occasionally winter, (6) winter visitants, and (7) those having been found only once or twice at the lake. It should be kept in mind that these categories apply to the birds at the lake and do not reflect their status in other parts of the state. For example, the Western Tanager is considered a migrant at the lake but in the state is a summer resident. Migrants are those birds that visit the lake usually twice a year as they pass to and from their breeding grounds. There are 37 species that have been assigned to that status (Table 5). There are 6 species that are migrants, but our records show that occasionally they may remain here during the winter. These are the Solitary Sandpiper, Greater Yellowlegs, Lesser Yellowlegs, Least Sandpiper, Long-billed Dowitcher, and Marbled Godwit. Permanent residents are those found here all the year around. There are 47 species of this type (Table 6). Summer residents are those that are here during the spring, summer, and fall. Frequently they cannot stand very cold weather or have food habits closely associated with insects or other invertebrates not available during the colder parts of the year. Table 7 lists the 46 summer residents at Utah Lake. Occasionally, some summer residents may winter in the area, although most of their kind have left for more suitable habitats to the south. Twenty-eight species are in this category (Table 8). A few species spend their winter months here and then travel to other areas for breeding purposes. Twenty species are considered to be winter visitants (Table 9). Sixteen species have been recorded once or twice at the lake. They are usually rare visitors in the state as well as to the lake. The species in this group are the Red-necked Grebe, Brown Pelican, Common Egret, Wood Stork, White-fronted Goose, Wood Duck, White-winged Scoter, Red Knot, Herring Gull, Sabine's Gull, Black Swift, Chimney Swift, LeConte's Sparrow, Solitary

TABLE 3. Relative abundance of birds at Utah Lake.

Relative abundance	Species	Percent
Abundant	10	5
Common	76	37
Uncommon	44	22
Casual	55	27
Rare	19	9
Total	204°	

°Several species listed in more than one category.

TABLE 4. Habitat preferences of avian species at Utah Lake.

Habitat	Species
Open water	67
Marsh	101
Beaches	40
Wet meadow	128
Dry meadow	115

Vireo, Warbling Vireo, and Common Grackle. Table 10 summarizes this information.

Sixty-eight species breed at Utah Lake (Table 11). The earliest breeding species commence egg laying in late March and early April and include Double-crested Cormorant, Great Blue Heron, Canada Goose, and House Sparrow. The peak of the nesting season is in the month of May with some late-breeding species extending into July (Fig. 1).

The late nesters are Snowy Plover, Killdeer, Spotted Sandpiper, Mourning Dove, Willow Flycatcher, Yellow Warbler, Brown-headed Cowbird, Bobolink, and American Goldfinch.

There are four species of birds that are not native to the area and are now part of the permanent resident population. They are the Ring-necked Pheasant, Chukar, House Sparrow, and Starling.

Rock Island

A unique feature of Utah Lake is Rock Island. It formerly provided a nesting and resting habitat for a number of birds, but the rising level of the water in the lake during the 1970s completely inundated the island. The yearly fluctuations of the lake now result in the island being visible during part of the year and then disappearing as the water rises. It is not known how long the island has existed. Bee (1924–1962) mentioned the killing of pelicans on the island in 1890. Goodwin (1904:128) indicated that there were about 200 young pelicans on the island in 1904, and added that they ranged in size "from a half grown gosling, to that of a large fowl and larger." Nothing was recorded about the island for the 25-year interval between Goodwin's report and Cottam's (1929c) list of the water birds of Utah Lake. Cottam (1935) reported great numbers of California Gulls nesting on the island and that the colony had been on the increase for a number of years. Bee (1924–1962) and Hayward (1936–present) report a number of visits to the island in the 1930s. Hayward (1935a) discussed the Caspian Tern colony on the island and reported that from 1927 to 1933 the tern colony diminished in size as the California Gull colony increased. Beck (1942b) gave the best physical description of the island and also included an aerial photograph [p. 105]. He in-

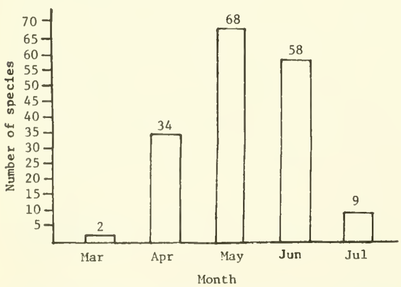

Fig. 10. Breeding chronology of birds at Utah Lake. Species counted in each month that they were found breeding.

TABLE 5. Migrant species at Utah Lake. For scientific names see Table 1.

1. Common Loon
2. Horned Grebe
3. Snow Goose
4. Greater Scaup
5. Lesser Scaup
6. Oldsquaw
7. Osprey
8. Sandhill Crane
9. Semipalmated Plover
10. Black-bellied Plover
11. Baird's Sandpiper
12. Dunlin
13. Semipalmated Sandpiper
14. Western Sandpiper
15. Sanderling
16. Northern Phalarope
17. Glaucous Gull
18. Bonaparte's Gull
19. Common Tern
20. Vaux's Swift
21. White-throated Swift
22. Lewis's Woodpecker
23. Purple Martin
24. Mountain Bluebird
25. Townsend's Solitaire
26. Swainson's Thrush
27. Hermit Thrush
28. Lincoln's Sparrow
29. Chipping Sparrow
30. Western Tanager
31. Nashville Warbler
32. Yellow-rumped Warbler
33. MacGillivray's Warbler
34. Wilson's Warbler
35. Evening Grosbeak
36. Pinon Jay
37. Scrub Jay

dicated that there were four main plant communities on the island. Beck estimated that in a three-year period (1940–1942) the California Gull population increased from 22,730 to 68,744. He considered this colony to be one of the largest California Gull colonies in the world. Behle (1945) visited Rock Island 26 May 1932 and reported 12 species of birds on the island at that time. Sugden (1947) reported nesting California Gulls on the island in May of 1945 and 1946. In six nests, he found an exotic egg in the gull's nest. Each of five nests had a pheasant egg besides the gull eggs, and one nest was found with a coot egg. In November 1951 a flock of 25 Snow Buntings were seen at Rock Island by Floyd Thompson. One was found dead and was presumed to have been shot the previous day by a duck hunter (Lockerbie and Behle 1952). In 1957 Bee (1924–1962) reported 6 species of birds on the island in June and noted that the California Gulls had completed their nesting.

Table 6. Permanent residents at Utah Lake. For scientific name see Table 1.

1. Pied-bill Grebe
2. Mallard
3. Gadwall
4. Pintail
5. Green-winged Teal
6. Blue-winged Teal
7. Red-breasted Merganser
8. Sharp-shinned Hawk
9. Red-tailed Hawk
10. Swainson's Hawk
11. Golden Eagle
12. Marsh Hawk
13. Prairie Falcon
14. Peregrine Falcon
15. Merlin
16. American Kestrel
17. Ring-necked Pheasant
18. Chukar
19. Virginia Rail
20. Sora
21. Killdeer
22. Common Snipe
23. Screech Owl
24. Great Horned Owl
25. Long-eared Owl
26. Short-eared Owl
27. Belted Kingfisher
28. Common Flicker
29. Hairy Woodpecker
30. Downy Woodpecker
31. Horned Lark
32. Dipper
33. Rock Wren
34. Long-billed Marsh Wren
35. American Robin
36. Ruby-crowned Kinglet
37. Song Sparrow
38. Rufous-sided Towhee
39. Red-winged Blackbird
40. Western Meadowlark
41. Brewer's Blackbird
42. American Goldfinch
43. Cassin's Finch
44. House Sparrow
45. Starling
46. Black-billed Magpie
47. Raven

Table 7. Summer residents at Utah Lake. For scientific name see Table 1.

1. White Pelican
2. Cattle Egret
3. Snowy Egret
4. Turkey Vulture
5. Cooper's Hawk
6. Common Gallinule
7. Snowy Plover
8. Spotted Sandpiper
9. Black-necked Stilt
10. Forster's Tern
11. Caspian Tern
12. Black Tern
13. Common Nighthawk
14. Broad-tailed Hummingbird
15. Eastern Kingbird
16. Western Kingbird
17. Say's Phoebe
18. Willow Flycatcher
19. Gray Flycatcher
20. Western Wood Pewee
21. Violet-green Swallow
22. Tree Swallow
23. Rough-winged Swallow
24. Bank Swallow
25. Barn Swallow
26. Cliff Swallow
27. House Wren
28. Mockingbird
29. Sage Thrasher
30. Savannah Sparrow
31. Vesper Sparrow
32. Lark Sparrow
33. Sage Sparrow
34. Green-tailed Towhee
35. Black-headed Grosbeak
36. Blue Grosbeak
37. Lazuli Bunting
38. Virginia's Warbler
39. Yellow Warbler
40. Black-throated Gray Warbler
41. Townsend's Warbler
42. Common Yellowthroat
43. Northern Oriole
44. Brown-headed Cowbird
45. Bobolink
46. Cassin's Finch

He mentioned the presence of Forster's Terns and Black Terns, but no Caspian Terns. It has been only in the last three or four years that the island has been completely inundated. As the lake recedes, in years to come it may once more become an area that birds may use. The increased use of the lake as a recreational area with larger numbers of motor boats may result in the area being less useful to wildlife than it has been in the past. The foregoing reports indicate that 18 species of birds have been observed on the island. The breeding and nonbreeding species are listed in Table 12.

During the years 1940–1944, Vasco M. Tanner and other members of the Department of Zoology at Brigham Young University banded young California Gulls on Rock Island. Regular aluminum U.S. Fish and Wildlife bands were used plus red- and yellow-colored bands in various combinations to distinguish the years the birds were banded. A total of 2316 birds were banded, and of this number 128 were reported as being seen, captured, or found dead, a 5.5 percent recovery of the banded birds (Tanner 1941, 1947, Tanner and Beck 1942). Table 13 summarizes the banding data for the four-year period.

The Future of Utah Lake

Human impact will continue to be a factor affecting the avifauna of the lake. The degree of impact can be great or small depending upon the manner in which Utah Lake will be managed in the future. The lake will remain a multipurpose unit involved in furnishing water to Salt Lake Valley, providing a recreational area, supporting populations of wildlife, and being an object of beauty and inspiration to those who appreciate the wonders of nature. At the present time no one agency or organization is actively involved in looking at the lake as a whole and considering its many uses. The lake water users have their objectives and aims in mind

TABLE 8. Summer residents that may occasionally winter at Utah Lake. For scientific names see Table 1.

1. Eared Grebe
2. Western Grebe
3. Double-crested Cormorant
4. Great Blue Heron
5. Black-crowned Night Heron
6. American Bittern
7. White-faced Ibis
8. Canada Goose
9. Cinnamon Teal
10. American Wigeon
11. Northern Shoveler
12. Redhead
13. Canvasback
14. Ruddy Duck
15. Ferruginous Hawk
16. American Coot
17. Long-billed Curlew
18. Willet
19. American Avocet
20. Wilson's Phalarope
21. California Gull
22. Franklin's Gull
23. Mourning Dove
24. Burrowing Owl
25. Loggerhead Shrike
26. Blue-gray Gnatcatcher
27. Orange-crowned Warbler
28. Yellow-headed Blackbird

TABLE 9. Winter visitants at Utah Lake. For scientific names see Table 1.

1. Whistling Swan
2. Black Duck
3. Ring-necked Duck
4. Common Goldeneye
5. Barrow's Goldeneye
6. Bufflehead
7. Hooded Merganser
8. Common Merganser
9. Rough-legged Hawk
10. Bald Eagle
11. Ring-billed Gull
12. Water Pipit
13. Northern Shrike
14. Black-capped Chickadee
15. Snow-Bunting
16. White-crowned Sparrow
17. Dark-eyed Junco
18. Tree Sparrow
19. Pine Siskin
20. Common Crow

TABLE 10. Seasonal occurrence of birds at Utah Lake.

Status	Number	Percent
Migrants	37	19
Migrants that occasionally winter	6	3
Permanent residents	47	24
Summer residents	46	23
Summer residents that occasionally winter	28	14
Winter visitants	20	10
Occasional visitants	16	8
	200	

TABLE 11. Nesting species at Utah Lake. For scientific names see Table 2.

	Nests during				
	Mar	Apr	May	Jun	Jul
1. Eared Grebe			----	----	
2. Western Grebe		----	----	----	
3. Pied-billed Grebe		----	----	----	
4. White Pelican			----	----	
5. Double-crested Cormorant	----	----	----		
6. Great Blue Heron		----	----		
7. Cattle Egret			----	----	
8. Snowy Egret		----	----	----	
9. Black-crowned Night Heron		----	----		
10. American Bittern			----	----	
11. White-faced Ibis			----	----	
12. Canada Goose		----	----	----	
13. Mallard		----	----	----	
14. Gadwall			----	----	
15. Pintail		----	----		
16. Green-winged Teal		----	----	----	
17. Blue-winged Teal			----	----	
18. Cinnamon Teal			----	----	
19. Northern Shoveler		----	----	----	
20. Redhead		----	----		
21. Ruddy Duck			----	----	
22. Marsh Hawk		----	----	----	
23. Ring-necked Pheasant			----	----	
24. Sandhill Crane			----		
25. Virginia Rail		----	----	----	
26. Sora			----	----	
27. Common Gallinule			----	----	
28. American Coot		----	----	----	
29. Snowy Plover		----	----	----	----
30. Killdeer		----	----	----	----
31. Common Snipe		----	----	----	
32. Long-billed Curlew		----	----	----	
33. Spotted Sandpiper			----	----	----
34. Willet			----	----	
35. American Avocet		----	----	----	
36. Black-necked Stilt			----	----	
37. Wilson's Phalarope			----	----	
38. California Gull		----	----	----	
39. Forster's Tern			----	----	
40. Caspian Tern			----	----	
41. Black Tern			----	----	
42. Mourning Dove			----	----	----
43. Long-eared Owl		----	----		
44. Short-eared Owl		----	----	----	
45. Common Night Hawk			----	----	
46. Common Flicker		----	----	----	
47. Eastern Kingbird			----	----	
48. Say's Phoebe		----	----	----	
49. Willow Flycatcher			----	----	----
50. Rough-winged Swallow			----	----	
51. Bank Swallow			----	----	
52. Barn Swallow		----	----	----	
53. Long-billed Marsh Wren		----	----	----	
54. American Robin		----	----		
55. Song Sparrow		----	----		
56. Yellow Warbler			----	----	----
57. Common Yellowthroat		----	----	----	

Table 11 continued.

	Nests during				
	Mar	Apr	May	Jun	Jul
58. Yellow-headed Blackbird			---- ---- ----	---- ---- ----	
59. Red-winged Blackbird			--- ----	---- ---- ----	
60. Western Meadowlark		---- ----	---- ----	----	
61. Brewer's Blackbird			---- ----	----	
62. Brown-headed Cowbird			---- ----	---- ---- ----	
63. Bobolink			--- ----	---- ---- ----	
64. American Goldfinch			--- ----	---- ---- ----	----
65. House Sparrow	--- ----	---- ---- ----	---- ----	---- -------	
66. Starling		---- ----	---- ----	----	
67. Black-billed Magpie		---- ----	---- ----		
68. Common Crow		--- ----	-------		

TABLE 12. Birds of Rock Island, Utah Lake, Utah. For scientific names see Table 1.

Breeding species	Nonbreeding species
1. White Pelican	1. Double-crested Cormorant
2. Canada Goose	2. Snowy Plover
3. Mallard	3. Willet
4. Pintail	4. Sanderling
5. Killdeer	5. American Avocet
6. Spotted Sandpiper	6. Snow Bunting
7. California Gull	7. Yellow Warbler
8. Forster's Tern	
9. Caspian Tern	
10. Black Tern	
11. Song Sparrow	

TABLE 13. Banding results of California Gulls at Rock Island, Utah Lake, Utah, 1940–1944.

Year	No. banded	British Columbia	WA	OR	CA	Baja California	Mexico	NV	ID	UT	WY	Total recoveries
1940	1,000			2	10		1	1	1	28	1	44
1941	1,000	1	5	4	12	1	2			57		82
1942	300			1						1		2
1944	16											
Total	2,316	1	5	7	22	1	3	1	1	86	1	128

as do the municipalities that border the lake and the Division of Wildlife Resources, who by state law are responsible for the wildlife in, on, and around the lake. Shall each agency continue to follow its course of action without consulting or being aware of the objectives of other involved parties? To do so would cause, in time, utter chaos as the demands of each agency upon the lake become greater. Careful consideration needs to be given now to the multifaceted nature of Utah Lake. Some of the problems concerned with the management of the lake are briefly mentioned.

Conservative projections of population growth in Utah and Salt Lake Valleys indicate that many more thousands of people will be living here by the year 2000. More people will necessitate the continued upgrading of wastewater plants in the various communities so that water quality will be maintained in the lake. Increased population will mean increased use of the lake for irrigation, industry, culinary purposes, fishing,

Fig. 9. Marsh Hawk. Photo by R. J. Erwin.

boating, waterskiing, picnicking, and hunting. Some of these recreational needs are being provided by the Utah Lake State Park at the mouth of Provo River and the marinas being developed by the cities of American Fork and Orem.

Provo City has been contemplating an increase in the number and length of runways at the Provo Airport to accommodate larger aircraft. One proposal is to increase the runways southward into the Provo Bay area. The Bureau of Reclamation has as part of the Central Utah Project the diking and draining of Provo and Goshen Bays to reclaim land and reduce evaporation from the lake. As the population of Salt Lake Valley increases, their demands for water for irrigation, industry, and culinary use will become greater. The Division of Wildlife Resources is concerned with how the greater use of the lake will affect its wildlife.

These problems and many others need to be considered. Can all the demands put upon the lake be satisfied? Should the airport runways be extended into the nesting habitat of ducks, geese, and colonial water birds? Is more land and water more important than breeding habitat for wildlife? Can Salt Lake Valley drain from the lake level without considering the needs for recreation and other interests in Utah Valley? Should the Division of Wildlife Resources develop wildlife management areas to protect and provide more breeding and resting habitat? Should private organizations such as the Audubon Society or other groups be encouraged to develop wildlife sanctuaries? Should more marinas be constructed for increased boating and associated activities?

Is there a way that all the groups interested in Utah Lake can function together so that a unified plan may be formulated—not an agency that would dictate what should be done, but one that would bring interested groups together so that an interplay of ideas, objectives, and plans could be discussed and problems resolved? Fortunately, there is such an agency available. In 1973 the Utah State Legislature enacted the Provo-Jordan River Parkway Authority (State Lands 1973). This legislation became part of the Utah Code Annotated Section 65-10-1 and is as follows:

There is created within the department of natural resources a division to be known as the Provo-Jordan River parkway authority and the board of the Provo-Jordan River parkway authority for the purpose of establishing and coordinating programs for the development of rec-

reational areas, water conservation, flood control, reclamation, and wildlife resources on or along the Provo and Jordan Rivers and their tributaries.

Does Utah Lake fit into this legislation? Considerable discussion has been carried on concerning this question, and the answer is that Utah Lake is an integral part of the Provo-Jordan River parkway plan.

The problems that confront us at the present time need to be discussed and resolved for the sake of Utah Lake. The sooner the interested parties can be brought together and made aware of all the problems, the sooner they may be solved. Utah Lake is too valuable an asset to be allowed to deteriorate or be exploited by one group over another. Only cooperation and consideration by all parties can solve the problems that confront us at this time.

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